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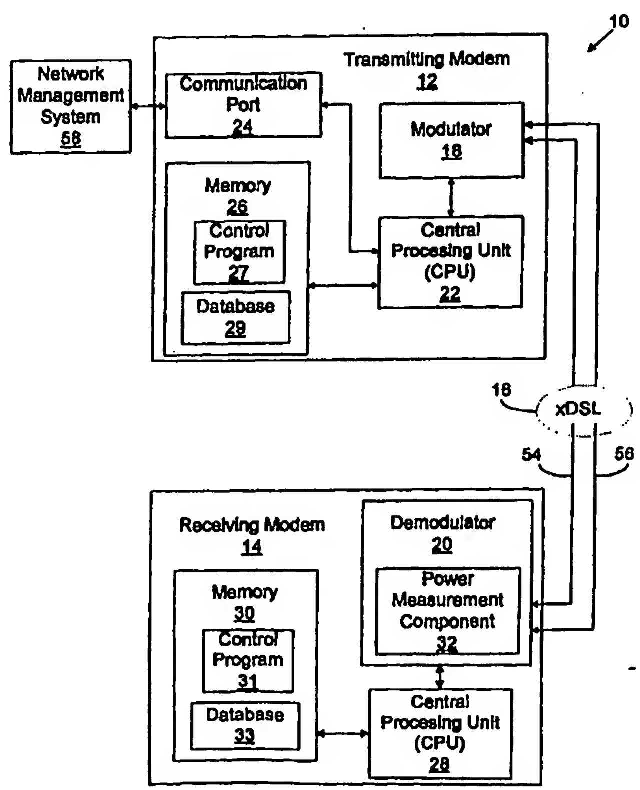
(54) Title: PERFORMANCE CUSTOMIZATION SYSTEM AND PROCESS FOR OPTIMIZING xDSL PERFORMANCE

(57) Abstract

A system and process for customizing the performance of an xDSL communication system (10) in which a transmitting modem (12) and a receiving modem (14) will negotiate a performance parameter for adjustment. The receiving modem (14) measures the net signal to noise ratio on the xDSL loop (16) and, based on that measurement, sends a request to the transmitting modem (12) to make a specific adjustment to the selected performance parameter. The transmitting modem (12) will make the adjustment upon receipt of the request from the receiving modem (14). In a preferred embodiment, the modems will choose either the data rate or the transmission power level as the performance parameter for adjustement. In a multiple xDSL system in which the xDSLs affect each other's performance through cross talk, the present invention allows a first modem pair to instigate a transmission power reduction, which will in turn allow a second modem pair to either increase its present data rate or decrease its transmission power. Through this combination of transmission power adaptation and data rate adaptation, it is possible to reduce the performance variance between the individual communication sessions or customize the performance profile according to specific customer requirements.



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TITLE OF THE INVENTION

Performance Customization System And Process For Optimizing xDSL Performance

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U. S. Provisional Application No. 60/050,564, entitled "Power Adaptive xDSL," filed June 23, 1997 (attorney docket no.: 61605-8620), which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates generally to the field of digital subscriber lines (DSLs), and more particularly, to a performance customization system and method for optimizing DSL performance as measured by such factors as throughput, power consumption, and loop length.

With the explosion in the growth of Internet usage among both businesses and households, telephone companies have been pressured to provide affordable, high bandwidth access that will support high-speed multimedia services, such as video on demand, high speed Internet access, and video conferencing. To meet this demand, telephone companies are increasingly turning to DSL technology. DSL, while having several different embodiments, can provide throughput rates over 400 times faster than that available through traditional 14.4 kbps modems. For example, the following manifestations of DSL technology are either available today or are currently being tested on a trial basis: Asymmetric Digital Subscriber Line (ADSL), which has a throughput of 32 kbps to 8.192 Mbps downstream to the customer and 32 kbps to 1.088 Mbps upstream to the network; Rate Adaptive Asymmetric Digital Subscriber Line (RADSL), which is a rate adaptive variation of ADSL; High-bit-rate Digital Subscriber Line (HDSL), which offers full duplex throughput at T1 (1.544 Mbps) or E1 (2.048 Mbps) data rates; Symmetric Digital Subscriber Line (SDSL), which provides bi-directional throughput at data rates ranging from 160 Kbps - 2.084 Mbps; and Very high-bit-rate Digital Subscriber Line (VDSL), which provides high data rates for customers close to the central office (*e.g.*, 51 Mbps for subscribers within

1000 feet). But most importantly, xDSL offers these high data rates over a standard copper telephone line. Thus, with such a large, embedded copper network already in place, network operators view xDSL technology as a means for extending the life of their investment in copper by many years.

Inasmuch as xDSL is deployed over the copper network, it is susceptible to the same unwanted noise signals that plague traditional copper based communication systems. Noise can be generated by components both internal to the communication system, such as resistors and solid state devices, and sources external to the communication system, such as atmospheric noise, high-voltage power lines and electric motors.

It is well known from information theory that the capacity of a channel (*i.e.*, maximum data rate) is directly related to the logarithm of the ratio of the signal power to the noise power on the channel. Therefore, to support the high data rates associated with xDSL, it would seem desirable to boost transmission power levels to boost the signal to noise ratio. As discussed in the foregoing, however, most xDSL systems operate across a broad range of data rates. Thus, if the transmission power level is statically set to support the highest rate possible, this will result in a waste of power for data sessions running at lower throughputs. Moreover, high transmission power levels unfortunately contribute to a phenomenon known as crosstalk, which is perhaps the most common and troubling source of noise in a network.

Crosstalk is defined as the cross coupling of electromagnetic energy between adjacent copper loops in the same cable bundle or binder. Crosstalk can be categorized in one of two forms: Near end crosstalk, commonly referred to as NEXT, is the most significant because the high energy signal from an adjacent system can induce relatively significant crosstalk into the primary signal. The other form is far end crosstalk or FEXT. FEXT is typically less of an issue because the far end interfering signal is attenuated as it traverses the loop. Crosstalk is a dominant factor in the performance of many systems. As a result, xDSL system performance is often stated relative to "in the presence of other systems" that may introduce crosstalk. Therefore, in central office (CO) environments where many xDSL loops or other circuits are bundled together in the same cable binder, it is often desirable to minimize

transmit power levels to the lowest levels possible that will still support the desired data rates to reduce the effects of crosstalk between the loops.

Alternatively, where maximum throughput is sought, it becomes desirable to maintain the transmit power level of a given xDSL communication session thereby allowing the data rate to be maximized within the limitations imposed by the noise characteristics of the channel. Optimization of xDSL performance in a central office environment would typically require a combination of both power reduction on some channels and increased throughput or data rates on other channels.

In addition to crosstalk, there may be other reasons to adapt power levels. One of these is to reduce unwanted noise created by the system itself. Certain impairments on the copper loop, such as bridged taps (an unterminated parallel length of wire) may create reflections and distortion energy that can reduce the overall performance of the system. Reducing the power in a frequency band that creates distortion energy or increasing the power in a band that does not create distortion energy can improve the performance of the overall system.

In view of the foregoing discussion, what is sought is an xDSL system and process that dynamically adjust the transmit power levels, data rates, and other defined performance parameters of one or more specific communication sessions to customize overall system performance.

SUMMARY OF THE INVENTION

Certain advantages and novel features of the invention will be set forth in the description that follows and will become apparent to those skilled in the art upon examination of the following or may be learned with the practice of the invention.

The present invention is generally directed to a performance customization system and process for optimizing xDSL performance. Broadly stated, an improved receiving modem according to the present invention includes negotiating means that the receiving modem uses to negotiate with a transmitting modem to select a particular xDSL performance parameter to be optimized. In addition, the receiving modem includes means that are used to calculate the signal to noise ratio on the

xDSL. Finally. the receiving modem includes means capable of requesting an adjustment in the selected performance parameter.

According to another aspect of the invention, an improved transmitting modem is disclosed that includes negotiating means used to negotiate with a receiving modem to select an xDSL performance parameter to be optimized. The transmitting modem further includes means responsive to performance parameter adjustment requests that are sent from a receiving modem. Further means are included in the transmitting modem for making the requested adjustment to the xDSL performance parameter.

The invention can also be viewed as providing a method for customizing the performance characteristics of an xDSL receiving modem. In this regard, the method can be broadly summarized by the following steps: The receiving modem negotiates with a transmitting modem to select an xDSL performance parameter for optimization. A net signal to noise ratio is calculated and, based on this result, an adjustment request is made for the selected xDSL performance parameter.

Similarly, the invention provides a method for customizing the performance characteristics of an xDSL transmitting modem. The method can be broadly summarized as follows: The transmitting modem negotiates with a receiving modem to select an xDSL performance parameter for optimization. An adjustment request for the selected xDSL performance parameter is received and, based on this request, the performance parameter is adjusted.

According to a preferred embodiment of the invention, the modems will choose either the data rate or the transmission power level as the performance parameter for adjustment. The non-selected performance parameter is assigned a fixed value while the selected performance parameter will undergo adjustment until the system operates at a data rate that is marginally supported by the transmission power level.

In a multiple xDSL system in which the xDSLs affect each others' performance through crosstalk, the present invention allows a first modem pair to instigate a transmission power reduction, which will in turn allow a second modem pair to either increase its present data rate or decrease its transmission power.

Through this combination of transmission power adaptation and data rate adaptation, it is possible to reduce the performance variance between the individual communication sessions or customize the performance profile according to specific customer requirements.

Additional advantages will become apparent from a consideration of the following description and drawings:

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of a prior art xDSL communication system;

FIG. 2 is a detailed block diagram of the xDSL performance customization system in accordance with the present invention;

FIG. 3 is a transmit power level optimization flow chart for the xDSL performance customization system of FIG. 2;

FIG. 4 is a data rate optimization flow chart for the xDSL performance customization system of FIG 2; and

FIG. 5 is a block diagram illustrating the application of the xDSL performance customization system in an environment where multiple xDSL loops are bundled together.

DETAILED DESCRIPTION OF THE INVENTION

While the invention is susceptible to various modifications and alternative forms, a specific embodiment thereof is shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular form disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

A general model for a prior art xDSL communication system 8 is illustrated in the block diagram of FIG. 1. The system comprises a transmitting modem 11 and a

receiving modem 13 that communicate with one another over an xDSL 16. Transmitting modem 11, through the use of a modulator, uses a message signal, generally known as a modulating or baseband signal, to modulate a carrier signal to produce what is commonly referred to as a modulated signal. As in any data transmission event, however, the signal received by a demodulator at receiving modem 13 will consist of the modulated signal, modified by distortions imposed by the transmission system, plus noise that is inserted between transmission and reception.

Noise can be divided into four categories: thermal noise, intermodulation noise, crosstalk and impulse noise. Thermal noise is due to thermal agitation of electrons in a conductor and is a function of temperature. This type of noise is present in all electronic devices and transmission media and is usually referred to as white noise, inasmuch as it is uniformly distributed across the frequency spectrum. A second type of noise, known as intermodulation noise, occurs when signals at different transmission frequencies share the same transmission medium. The effect of intermodulation noise is to produce signals at a frequency that is the sum or difference of two original frequencies. Crosstalk, which was discussed hereinbefore, can be broadly described as the unwanted coupling of signals between signal paths. The last type of noise, impulse noise, is the most unpredictable. Impulse noise consists of irregular pulses or noise spikes of short duration that are typically generated from external electromagnetic sources such as lightning, electric machinery and/or faults and flaws in the communication system.

Measures can be taken to counteract or at least minimize the effects of intermodulation and crosstalk noise, but thermal and impulse noise are ever present in virtually any electronic, copper based communication system. Therefore, for demodulator 20 to demodulate the modulated signal to obtain the original message signal, the ratio of the modulated signal power to the noise signal power must exceed a certain level. Typically, this ratio is referred to as the signal-to-noise (S/N) ratio and is reported in decibels according to EQ. 1 as follows:

$$(S/N)_{dB} = 10 \log (\text{signal power} / \text{noise power}) \qquad \text{EQ. 1}$$

Moreover, the maximum rate at which data can be transmitted across xDSL 16 is directly related to the logarithm of the ratio of the signal power to the noise power on the channel as expressed in EQ. 2 where the data rate is expressed in bits per second and W represents the bandwidth of the channel in hertz as follows:

$$\text{data rate}_{bps} = W \log_2(1 + (\text{signal power} / \text{noise power})) \qquad \text{EQ. 2}$$

Nevertheless, simply boosting the transmit power level at transmitting modem 11 to its maximum value to support the high data rates of an xDSL communication session may result in unnecessary power consumption for data sessions running at lower throughputs as discussed hereinbefore. The present invention overcomes this problem through dynamic adaptation of the transmission power level.

With reference now to FIGS. 2 and 3, transmission power adaptation according to the present invention will be discussed. The simplex communication system 10 of FIG. 2, comprising transmitting modem 12 and receiving modem 14, is used for simplicity. The principles discussed herein can readily be extended to a duplex environment. According to the xDSL communication system 10 depicted in FIG. 2, transmitting modem 12 comprises a central processing unit (CPU) 22 in communication with modulator 18, communication port 24 and memory 26. Memory 26 holds software control program 27 and database 29. Similarly, receiving modem 14 comprises CPU 28 in communication with demodulator 20 and memory 30. Memory 30, likewise holds software control program 31 and database 33. Demodulator 20 also comprises power measurement component 32. Control programs 27 and 31, in conjunction with databases 29 and 33, are executed by CPUs 22 and 28 and provide the control logic for the processes to be discussed herein.

FIG. 3 provides a flow chart for transmit power adaptation according to the present invention. The process begins with step 34 in which a maximum data rate is negotiated between transmitting modem 12 and receiving modem 14. This negotiation can be carried out in a variety of ways. For example, receiving modem 14 could maintain a table of possible data rates in database 33, one of which is retrieved by control program 31 and then transmitted to transmitting modem 12 as part of an initialization procedure. Similarly, control program 27 in transmitting modem 12 could select a data rate from a table stored in database 29 for transmission to receiving

modem 14 as part of an initialization procedure. Regardless of which modem initiates the establishment of the maximum data rate, the two modems can exchange messages according to any desired protocol until a mutually agreed upon rate is arrived at.

Once a maximum data rate has been established, receiving modem 14 will determine the net S/N ratio. Again, this determination can be made using a variety of well known techniques. One common technique is for transmitting modem 12 to cease transmission for a specified period. During this silent period, power measurement component 32 reads the noise present on xDSL 16 and calculates the power spectral density (PSD) of the noise. Following the silent period, transmitting modem 12 transmits a test pattern of data at a default power level allowing power measurement component 32 to calculate the PSD of the modulated signal plus noise. The previously calculated noise component can then be subtracted from the combined noise plus signal measurement to compute the net S/N ratio.

In step 38, receiving modem 14 determines whether the previously calculated S/N ratio will support the data rate originally arrived at in step 34. Typically, this process will involve control program 31 indexing a table stored in database 33 in which minimum S/N ratios are correlated with a list of possible data transmission rates and retrieving the minimum S/N ratio required for the current data rate. This table can be constructed using EQ. 2, which was set forth previously. It should be noted, however, that EQ. 2 provides a theoretical maximum in which only thermal or white noise is accounted for. In practice, due to impulse noise, crosstalk, attenuation and delay distortion, the maximum throughput that can actually be achieved will be less. Therefore, the data rates entered into the table should be reduced by a suitable amount to account for these additional factors.

Control program 31 then compares the calculated S/N ratio with the minimum required S/N ratio retrieved from database 33. If the calculated S/N ratio exceeds the minimum required S/N ratio by more than a specific margin, receiving modem 14 will send a message to transmitting modem 12 requesting that the transmission power be decreased in step 40. As part of this message, receiving modem 14 could request a specific transmit power value or, for simplicity, transmitting modem 12 could be instructed to simply drop down to the next lower value in a table of possible transmit

power levels stored in database 29. If the calculated S/N ratio falls below the minimum required ratio by more than a specific margin, receiving modem 14 will send a message to transmitting modem 12 requesting that the transmission power be increased in step 42. Again, receiving modem 14 could request a specific transmit power value or, alternatively, transmitting modem 12 could simply move up to the next higher value in a table of possible transmit power levels. If transmitting modem is instructed to merely increment or decrement its transmit power to the next available level, the process will repeat itself in iterative fashion beginning with step 36 until the calculated S/N ratio falls within a predetermined range or margin about the minimum required ratio. This range or margin ensures that the two modems don't endlessly chase one another in trying to close in on a satisfactory power level to support a specific data rate. Alternatively, if transmitting modem 12 is provided with an absolute transmit power value from receiving modem 14, the process should complete after one iteration.

It will be appreciated by those skilled in the art that more advanced and precise techniques can be used to calculate the minimum transmit power level that will support a given data rate. For example, transmitting modem 12 could transmit a test data pattern at a starting power level which would then be verified by receiving modem 14 using any well known error detection technique. If the test pattern has fewer than a certain minimum threshold of bit errors, receiving modem 14 would instruct transmitting modem 12 to decrease the transmit power. Conversely, if the test pattern has more than the minimum threshold of bit errors, transmitting modem 12 would be instructed to increase the transmit power. Through successive iterations of this procedure, the transmit power should end up at the level that just supports the data rate.

The example of FIG. 3 is directed towards adapting or minimizing the transmission power level for a fixed data rate. Conversely, there will be circumstances, as discussed hereinbefore, where it is desirable to fix the transmission power level and then adapt or maximize the data rate for that power level. FIG. 4 provides a flow chart for data rate adaptation according to the present invention.

Referring now to FIGS. 2 and 4, the process begins with step 44 in which a minimum transmission power is negotiated between transmitting modem 12 and receiving modem 14. This negotiation can be carried out using the same approach discussed earlier with respect to data rate negotiation. That is, one or both of modems 12 and 18 could maintain tables in memories 26 and/or 30 that contain valid transmission power levels. One of the two modems 12 and 18 will propose a transmission power level to the other modem during an initialization procedure, and, using any desired protocol, the modems will exchange messages to arrive at an agreed upon minimum transmission power level.

Now that the minimum transmission power level has been established, receiving modem 14 will determine the net S/N ratio in step 46 in the same manner as discussed earlier with respect to step 36 of FIG. 3. During step 46, control program 27 in transmitting modem 12 will choose a default data rate, which is stored in database 29, for use as a starting point in the adaptation process. This initial data rate will then be transmitted to receiving modem 14 in a message.

In step 48, receiving modem 14 determines whether the calculated S/N ratio will support the initial data rate set by transmitting modem 12. Receiving modem 14 follows a similar procedure as that described earlier with respect to step 38 of FIG. 3. First, control program 31 uses the calculated S/N ratio to index the table stored in database 33 in which minimum S/N ratios are correlated with a list of possible data transmission rates and retrieves a maximum data rate. As part of the indexing procedure, control program 31 compares the calculated S/N ratio with the minimum required S/N ratio entries stored in database 33. When the calculated S/N ratio falls within a certain range or margin about a particular S/N ratio entry, the data rate associated with that entry will be retrieved. The margin or range value will be chosen based on the granularity of entries in the database to allow control program 31 to converge upon a choice. The margin or range is necessary because the calculated S/N ratio will rarely correspond exactly to a table entry.

Next, if the data rate retrieved from the table is greater than the initial data rate set by transmitting modem 12, receiving modem 14 could request in step 50 that transmitting modem 12 increase the data rate to the retrieved value or, alternatively,

transmitting modem 12 could be instructed to simply increment the data rate to the next higher value in a table of possible data rates stored in database 29. On the other hand, if the data rate retrieved from the table is less than the initial data rate set by transmitting modem 12, receiving modem 14 could request in step 52 that transmitting modem 12 decrease the data rate to the retrieved value or, alternatively, transmitting modem 12 could be instructed to simply decrement the data rate to the next lower value in a table of possible data rates stored in database 29.

Similar to the case of transmit power adaptation, if transmitting modem 12 is instructed to merely increment or decrement the data rate to the next available level, the data rate adaptation process will repeat itself in iterative fashion beginning with step 48 until the transmitted data rate converges upon the rate retrieved from the table in database 33. Alternatively, if transmitting modem 12 is provided with an absolute data rate value from receiving modem 14, the process should complete after one iteration.

While it is possible to practice both the transmit power adaptation method of FIG. 3 and the data rate adaptation method of FIG. 4 using in-band messaging between the two modems (*i.e.*, using xDSL data channel 54), in the preferred embodiment, embedded operational channel 56 (EOC) will be used instead. EOC 56 provides a low speed secondary channel on xDSL 16 that allows the aforementioned methods to be practiced simultaneously with ongoing data transmission. Instead of sending test data to calculate a S/N ratio at receiving modem 14, a S/N ratio can be calculated from a data transmission from an actual communication session.

Also, a typical application of the present invention will involve one of the two modems 12 and 14 being located at a central office (CO) or remote terminal (RT) site with the other modem being located at a customer site. This configuration allows the modem located at the CO, which, in FIG. 2, is transmitting modem 12, to be managed by network management system 58. Through network management system 58, the tables that comprise databases 29 and 33 can be downloaded through communication port 24 and periodically updated according to the current xDSL application. The modem located at the customer site, which is receiving modem 14 in the present example, can download the tables it needs for database 33 from transmitting modem

12. Moreover. a technician can enter a particular performance parameter to be optimized (*e.g.*, transmission power level or data throughput) and fix values for parameters that will not be optimized through network management system 58. Network management system 58 effectively eliminates negotiation steps 34 and 44 of FIGS. 3 and 4 respectively, in which the modems themselves select which performance parameters will receive fixed values and which performance parameter will be optimized.

It will be appreciated by those skilled in the art that the functionality provided through control programs 27, 31 and databases 29, 33 can also be implemented through hardware (*e.g.*, an application specific integrated circuit (ASIC) and supporting circuitry). Each implementation has its advantages, however. For example, hardware enjoys a speed and, arguably, a reliability advantage over software because hardware testing and verification methods are currently more advanced than software verification methods. On the other hand, software can be less expensive than customized hardware and offers greater flexibility in adding or modifying product features.

Further, the present invention comprising control programs 27, 31 and databases 29, 33 can be embodied in any computer-readable medium for use by or in connection with a computer-related system (*e.g.*, an embedded system such as a modem) or method. In this context of this document, a computer-readable medium is an electronic, magnetic, optical, semiconductor, or other physical device or means that can contain or store a computer program or data for use by or in connection with a computer-related system or method. Also, the computer program or data may be transferred to another computer-readable medium by any suitable process such as by scanning the computer-readable medium. Thus, the computer-readable medium could be paper or other suitable medium upon which the computer program can be printed, scanned with an optical scanner, and transferred into the computer's memory or storage.

Thus far, the principles of the present invention have been applied to a single pair of modems communicating in isolation. The advantages of the present invention,

however, are perhaps most impressive when these principles are applied to a modem pool environment.

As discussed earlier, crosstalk is one of the primary sources of noise in a communication system. Moreover, crosstalk is particularly debilitating in a modem pool environment where many xDSL loops and other circuits are bundled together in the same cable binder, which is standard practice in a CO. While increasing signal transmission power can improve the S/N ratio in a communication system, it unfortunately comes with the negative side effect of enhancing crosstalk with a neighboring system.

The present invention can optimize the performance of an entire modem pool system by reducing crosstalk stemming from unnecessary transmit power levels. Referring now to FIG. 5, a communication system is shown in which a first pair 10a of modems 12a and 14a communicating over xDSL 16a and a second pair 10b of modems 12b and 14b communicating over xDSL 16b suffer from crosstalk. The crosstalk results from xDSLs 16a and 16b being bundled together at one end in the same cable binder. Now, suppose transmitting modem 12a of first pair 10a is operating at a transmit power level that is greater than the minimum needed to support the current data rate. First pair 10a can then achieve a lower transmission power level using the process of FIG. 3 as described herein. The reduction in transmission power by first pair 10a has the effect of reducing the level of crosstalk noise that bleeds into second pair 10b. Therefore, second pair 10b can likewise negotiate a lower transmission power level because of the reduction in crosstalk even if second pair 62 was currently operating at an optimum performance level (*i.e.*, the transmission power is marginally sufficient to support the current data rate). In theory, this process could go on in perpetuity with both pairs alternately negotiating transmit power level reductions; however, this would be possible only in a system where crosstalk is the only noise component. In all practical systems, there will always be non-crosstalk noise that will place a lower limit on transmission power levels. Nevertheless, in systems in which crosstalk is the dominating noise factor, the power savings can be dramatic.

In the example just described. second pair 10b, which was initially operating at a marginal performance level, reduced its transmission power while maintaining its current data rate or throughput in response to the transmission power reduction by first pair 10a. Alternatively, second pair 10b could opt instead to increase its data rate using the process of FIG. 4 as previously discussed. In that circumstance, the entire system will enjoy an overall performance improvement comprising both a reduction in power consumption and an increase in throughput. It should be noted that in a multiple xDSL system, such as a modem pool, at least one of the individual communication links (*e.g.*, pairs in the preceding example) must be operating above its marginal performance level. That is, it must be using a transmission power level greater than the level necessary to support its current data rate. For systems comprising many communication pairs, a thorough performance improvement analysis would be highly complex and thus require a computer simulation. Nevertheless, it should be clear to the skilled practitioner that the performance of a large xDSL modem pool system can be tuned to attain a desired performance improvement through selective application of transmission power and data rate adaptation according to the present invention. Advantageously, network management system 58 can be used extensively by a technician to target those communication links that will benefit the most from power and/or data rate adaptation.

Note that through selective application of the xDSL performance customization principles discussed herein, the performance variance between xDSL communication pairs can be reduced. For example, recall the foregoing discussion with reference to FIG. 5 in which the second modem pair 10b had the option of undertaking a transmission power reduction or increasing its data rate in response to a transmit power reduction by the first modem pair 10a. Thus, assuming the first modem pair 10a was transmitting at a higher data rate than the second modem pair 10b, the throughput performance variance between the two pairs can be reduced by increasing the data rate of modem pair 10b.

The present invention has been discussed as applied generally to an xDSL comprising a data channel 54 and an EOC 56 (see FIG. 2). The principles disclosed, however, can be extended to the lower level modulation techniques used in xDSL

signaling. For example, rather than merely adapting transmission power uniformly across the entirety of the transmission spectrum, a frequency dependent version of the present invention can be implemented in which the same principles are applied to selected sub-bands within the spectrum. The concepts remain the same, except the receiver will now measure the net S/N ratio in each sub-band individually and negotiate the transmission power level and/or data rate within only that band of the xDSL data channel. This approach would be preferred for those xDSL systems using Discrete Multi-Tone (DMT) modulation in which the available bandwidth is divided into a set of independent, orthogonal sub-channels and then data is assigned to each sub-channel according to the channel quality. Similarly, the present invention can be applied to baseband systems by combining transmission power adaptation with precoding and adaptive pre-emphasis in which some parts of the signal are attenuated and other amplified according to frequency.

In the examples presented, two variables, transmission power level and data rate, were used as the optimization criteria. The present invention is not limited to the optimization of these two variables, however. Loop length is a third variable that can be optimized using the system and method of the present invention. It is well known that channel attenuation increases as a loop length increases. Thus, longer loop lengths will require a corresponding increase in transmission power level if the same data rate is to be maintained. The present invention provides the skilled practitioner with the flexibility of weighing such performance factors as power consumption, throughput and loop length in an xDSL communication against one another to develop a customized system having a performance profile tailored to the needs of a particular customer base. As customer needs change, the performance of the system can easily be altered to accommodate any new requirements.

In concluding the detailed description, it should be noted that it will be obvious to those skilled in the art that many variations and modifications can be made to the preferred embodiment without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.

CLAIMS

We claim:

1. A digital subscriber line (DSL) modem receiver having customizable performance characteristics, comprising:

means for negotiating a performance parameter for optimization;

means for determining a net signal to noise ratio; and

means for requesting an adjustment in said performance parameter based on said net signal to noise ratio.

2. The modem receiver of claim 1, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level.

3. The modem receiver of claim 1, wherein said means for determining comprises means for measuring a power spectral density of a signal on said DSL.

4. A method for customizing the performance characteristics of a digital subscriber line (DSL) modem receiver, comprising the steps of:

negotiating a performance parameter for optimization;

determining a net signal to noise ratio; and

requesting an adjustment in said performance parameter based on said net signal to noise ratio.

5. The method of claim 4, wherein said negotiating step comprises the steps of:

selecting said performance parameter from a plurality of possible performance parameters; and

fixing a value for each of said non-selected performance parameters.

6. The method of claim 5, wherein said selecting and fixing steps are performed by an external management system.

7. The method of claim 5, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level.

8. The method of claim 4, wherein said modem receiver receives data on a plurality of sub-channels and wherein said negotiating and determining steps are performed for each sub-channel used.

9. A digital subscriber line (DSL) modem transmitter having customizable performance characteristics, comprising:

means for negotiating a performance parameter for optimization;

means responsive to an adjustment request for said performance parameter; and

means for adjusting said performance parameter.

10. The modem transmitter of claim 9, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level.

11. A method for customizing the performance characteristics of a digital subscriber line (DSL) modem transmitter, comprising the steps of:

negotiating a performance parameter for optimization;

receiving a performance parameter adjustment request signal; and

adjusting said performance parameter.

12. The method of claim 11, wherein said negotiating step comprises the steps of:

selecting said performance parameter from a plurality of possible performance parameters; and

fixing a value for each of said non-selected performance parameters.

13. The method of claim 12, wherein said selecting and fixing steps are performed by an external management system.

14. The method of claim 12, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level

15. The method of claim 11, wherein said modem transmitter transmits data using a plurality of sub-channels and wherein said negotiating and adjusting steps are performed for each sub-channel used.

16. A method for customizing the performance of a communication system, said system comprising a transmitting modem and a receiving modem in communication over a digital subscriber line (DSL), said method comprising the steps of:

negotiating a performance parameter for optimization;

determining a net signal to noise ratio at said receiving modem;

said receiving modem requesting said transmitting modem to make an adjustment in said performance parameter based on said net signal to noise ratio; and

adjusting said performance parameter at said transmitting modem.

17. The method of claim 16, wherein said negotiating step comprises the steps of:

selecting said performance parameter from a plurality of possible performance parameters; and

fixing a value for each of said non-selected performance parameters.

18. The method of claim 17, wherein said selecting and fixing steps are performed by an external management system.

19. The method of claim 17, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level.

20. The method of claim 16, further comprising the step of:

repeating said determining, requesting and adjusting steps in iterative fashion until said system operates at a data rate marginally supported by a transmission power level.

21. The method of claim 16, wherein said negotiating and requesting steps are performed using out-of-band signaling on a low speed secondary channel.

22. The method of claim 16, wherein data are transmitted from said transmitting modem to said receiving modem using a plurality of sub-channels and wherein said negotiating, determining, requesting and adjusting steps are performed for each sub-channel used.

23. A method for customizing the performance of a communication system, said system comprising a first modem pair consisting of a first transmitting modem and a first receiving modem in communication with each other over a first digital subscriber line (DSL) and a second modem pair consisting of a second transmitting modem and a second receiving modem in communication with each other over a second DSL, said first and second DSLs affecting one another with crosstalk, said method comprising the steps of:

negotiating a first data rate between said first transmitting modem and said first receiving modem;

determining a first net signal to noise ratio at said first receiving modem;

said first receiving modem requesting said first transmitting modem to reduce a first transmission power level based on said first net signal to noise ratio; and

reducing said first transmission power level at said first transmitting modem until said first data rate between said first transmitting modem and said first receiving modem is marginally supported.

24. The method of claim 23, further comprising the steps of:

negotiating a second data rate between said second transmitting modem and said second receiving modem;

determining a second net signal to noise ratio at said second receiving modem;

said second receiving modem requesting said second transmitting modem to reduce a second transmission power level based on said second net signal to noise ratio; and

reducing said second transmission power level at said second transmitting modem until said second data rate between said second transmitting modem and said second receiving modem is marginally supported.

25. The method of claim 24, further comprising the step of:

repeating said determining, requesting and adjusting steps on said first modem pair and said second modem pair in iterative fashion until said transmission power levels on each modem pair marginally support said data rates on each modem pair.

26. The method of claim 24, wherein data are transmitted between said modems in said modem pairs using a plurality of sub-channels and wherein said negotiating, determining, requesting and adjusting steps are performed for each sub-channel used.

27. The method of claim 23, further comprising the steps of:

negotiating a second transmission power level between said second transmitting modem and said second receiving modem;

determining a second net signal to noise ratio at said second receiving modem;

said second receiving modem requesting said second transmitting modem to increase a second data rate based on said second net signal to noise ratio; and

increasing said second data rate between said second transmitting modem and said second receiving modem until said until said second data rate between said second transmitting modem and said second receiving modem is marginally supported.

28. A digital subscriber line (DSL) communication system having customizable performance characteristics, comprising:

means for negotiating a performance parameter for optimization between a transmitting modem and a receiving modem;

means for determining a net signal to noise ratio at said receiving modem;

means for requesting said transmitting modem to make an adjustment in said performance parameter based on said net signal to noise ratio; and

means for adjusting said performance parameter at said transmitting modem.

29. The system of claim 28, wherein said performance parameter is selected from the group consisting of a data rate and a transmission power level.

30. The system of claim 28, wherein said means for determining comprises means for measuring a power spectral density of a signal on said DSL.

31. A digital subscriber line (DSL) modem receiver, comprising:

a demodulator having a power spectral density measurement component, said demodulator in communication with said DSL;

a memory holding a control program and data;

a central processing unit (CPU) in communication with said demodulator and said memory;

said control program including the following control logic:

logic configured to negotiate a performance parameter for optimization;

logic configured to determine a net signal to noise ratio

logic configured to retrieve an entry from a data structure in which signal to noise ratios are correlated with performance parameter values;

logic configured to compare said retrieved entry with said signal to noise ratio calculation; and

logic configured to request an adjustment in said performance parameter.

32. A digital subscriber line (DSL) modem transmitter, comprising:

a memory holding a control program and data;

a central processing unit (CPU) in communication with said demodulator and said memory;

said control program including the following control logic:

logic configured to negotiate a performance parameter for optimization;

logic configured to receive an adjustment request for said performance parameter; and

logic configured to adjust said performance parameter.

33. A computer readable medium having a program and data for use in a digital subscriber line (DSL) modem receiver, said program comprising:

logic configured to negotiate a performance parameter for optimization;

logic configured to determine a net signal to noise ratio;

logic configured to retrieve an entry from a data structure in which signal to noise ratios are correlated with performance parameter values;

logic configured to compare said retrieved entry with said signal to noise ratio calculation; and

logic configured to request an adjustment in said performance parameter.

34. A computer readable medium having a program and data for use in a digital subscriber line (DSL) modem transmitter, said program comprising:

logic configured to negotiate a performance parameter for optimization;

logic configured to receive an adjustment request for said performance parameter; and

logic configured to adjust said performance parameter.

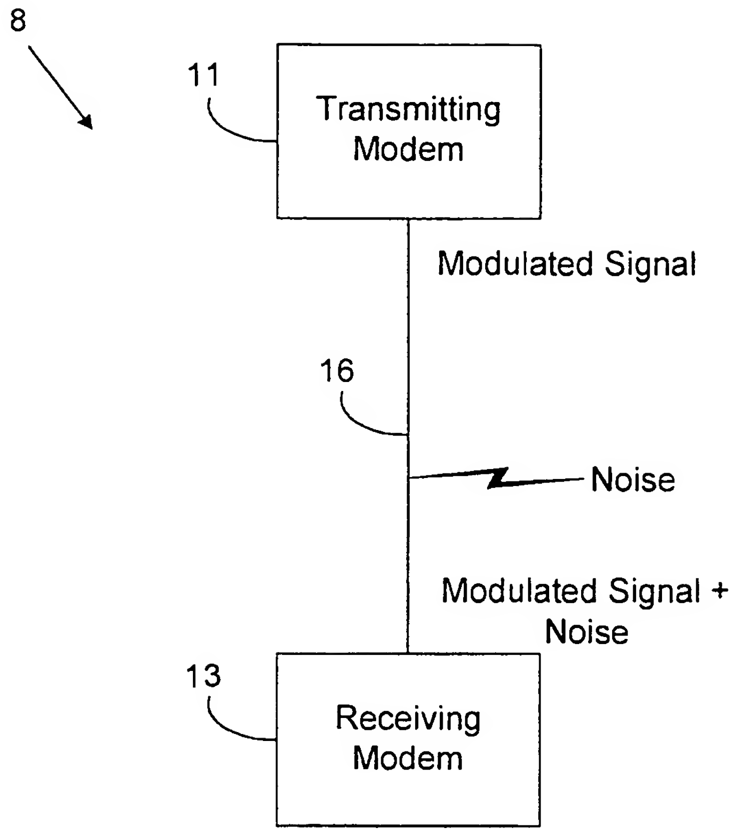

Fig. 1

Prior Art

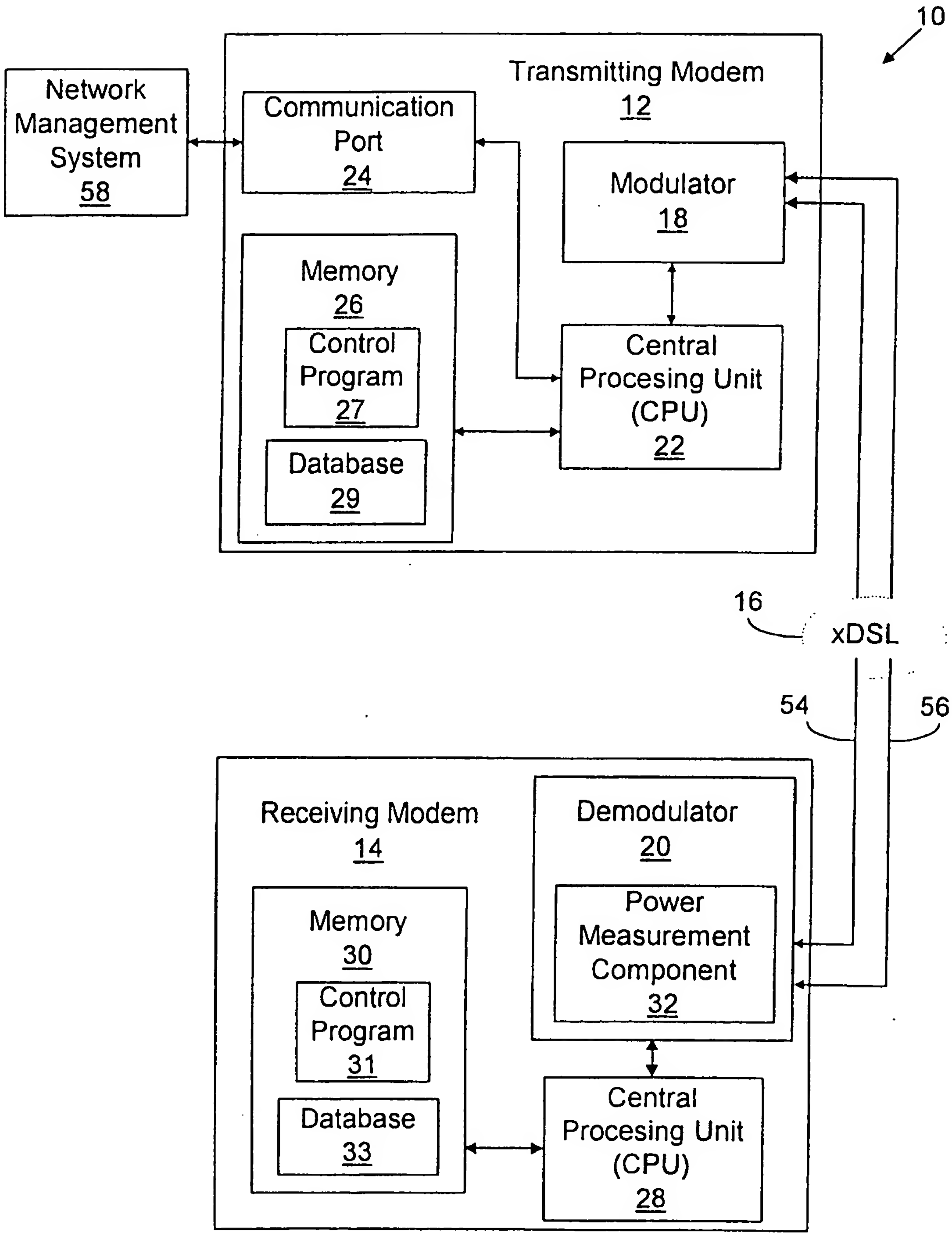
10
Network Management System 58
Transmitting Modem 12
Communication Port 24
Modulator 18
Memory 26
Control Program 27
Database 29
Central Procesing Unit (CPU) 22
16
xDSL
54
56
Receiving Modem 14
Demodulator 20
Power Measurement Component 32
Memory 30
Control Program 31
Database 33
Central Procesing Unit (CPU) 28

Fig. 2

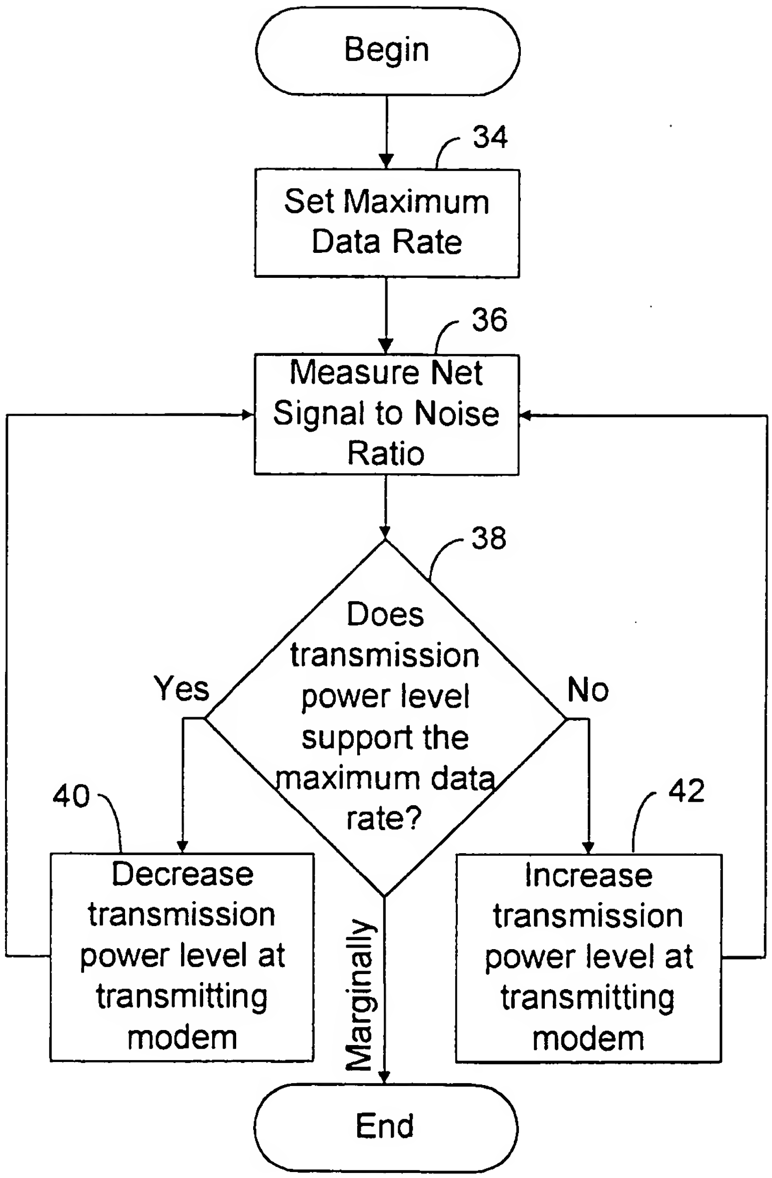
Begin
34
Set Maximum Data Rate
36
Measure Net Signal to Noise Ratio
38
Does transmission power level support the maximum data rate?
Yes
No
40
Decrease transmission power level at transmitting modem
42
Increase transmission power level at transmitting modem
Marginally
End

Fig. 3

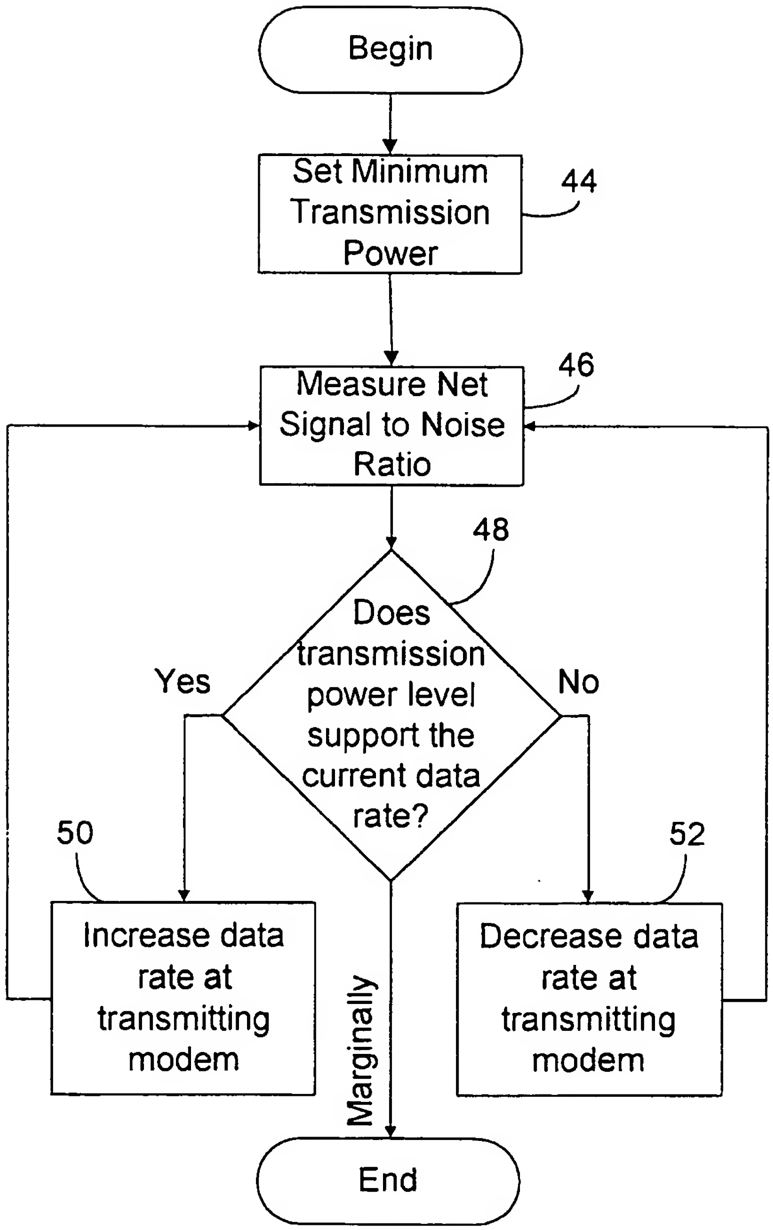
Begin
Set Minimum Transmission Power
44
Measure Net Signal to Noise Ratio
46
48
Does transmission power level support the current data rate?
Yes
No
50
52
Increase data rate at transmitting modem
Marginally
Decrease data rate at transmitting modem
End

Fig. 4

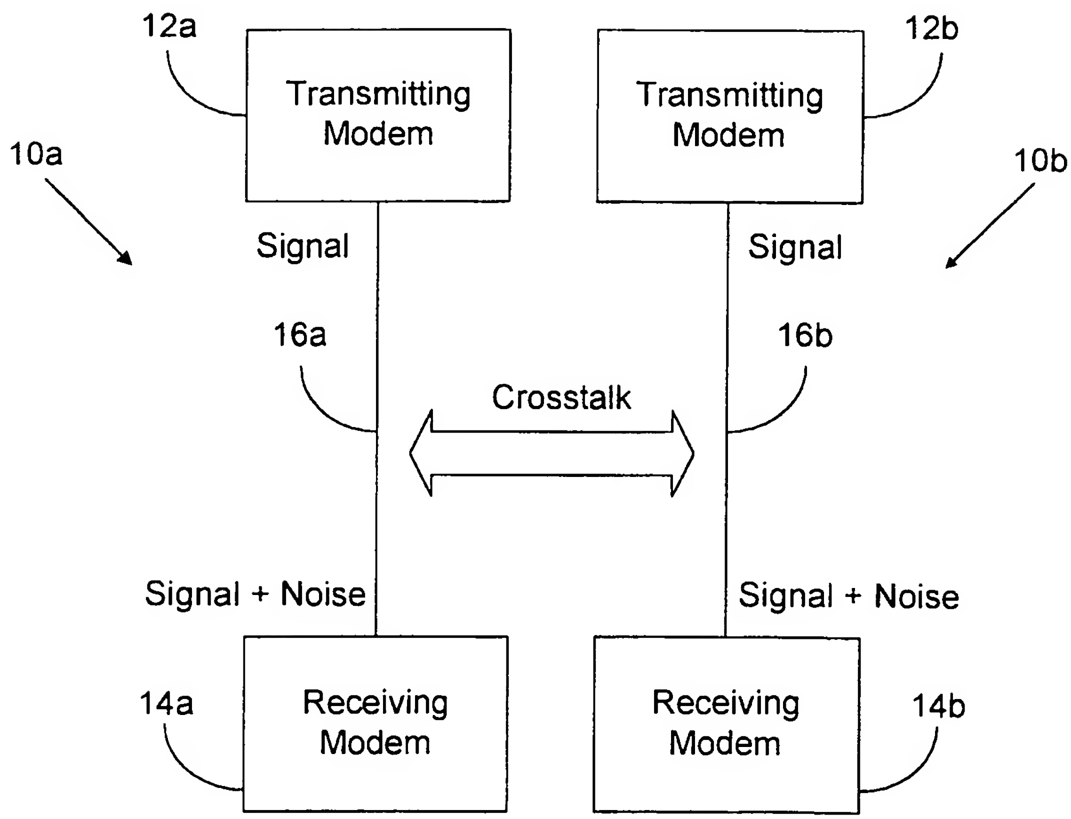
12a
Transmitting
Modem
12b
Transmitting
Modem
10a
10b
Signal
Signal
16a
16b
Crosstalk
Signal + Noise
Signal + Noise
14a
Receiving
Modem
Receiving
Modem
14b

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/13475

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04B 1/38; H04L 5/16
US CL :375/222
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 375/222, 225; 370/230, 231, 235, 252

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, E	US 5,802,446 A (GIORGI ET AL) 1 SEPTEMBER 1998, ABSTRACT, COLUMNS 1-2, CLAIMS 1-4	1-30
Y, P	US 5,726,765 A (YOSHIDA ET AL) 10 MARCH 1998, COL. 1, LINES 15-55.	1-30
Y, P	US 5,671,250 A (BREMER ET AL) 23 SEPTEMBER 1997, ABSTRACT, COL. 1, LINE 65 TO COL. 2, LINE 25.	1-30
Y	US 5,150,387 A (YOSHIKAWA ET AL) 22 SEPTEMBER 1992, COL. 3, LINES 6-23, CLAIMS 1 AND 6-9.	1-30

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
22 SEPTEMBER 1998	22 OCT 1998

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(54) Title: SPLITTERLESS MULTICARRIER MODEM

(57) Abstract

A modem for use in Digital Subscriber Line communications transmits and receives data over the local subscriber loop in common with voice information over the loop, while avoiding the need for voice/data splitters. The modem responds to disruptions associated with "disturbance events" such as on-hook to off-hook transitions and the like by rapidly switching between pre-stored channel parameter control sets defining communications over the loop under varying conditions. In addition to changing parameter control sets responsive to a disturbance event, the modem may also change transmission power levels and other system parameters such as frequency domain equalizer characteristics. Further, provisions are made for reduced bandwidth communications under selected conditions.

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SPLITTERLESS MULTICARRIER MODEM

Cross-reference to related applications:

This application is based in part on the following applications filed by one or more of the inventors herein:

U.S. Provisional Patent Application Serial No. 60/061,689, filed October 10, 1997 by Richard Gross, John Greszcuk, Dave Krinsky, Marcos Tzannes, and Michael Tzannes and entitled "Splitterless Multicarrier Modulation For High Speed Data Transport Over telephone Wires";

U.S. Provisional Patent Application Serial No. **** filed January 16, 1998 by Richard Gross and Michael Tzannes and entitled "Dual Rate Multicarrier Transmission System In A Splitterless Configuration";

U.S. Provisional Patent Application Serial No. *** filed January 21, 1998 by Richard Gross, Marcos Tzannes and Michael Tzannes and entitled 'Dual Rate Multicarrier Transmission System In A Splitterless Configuration".

U.S. Provisional Patent Application Serial No. *** filed January 26, 1998 by Richard Gross, Marcos Tzannes and Michael Tzannes and entitled "Multicarrier SystemWith Dynamic Power Levels".

The disclosures of these applications are incorporated by reference herein in their entirety.

Background of the invention

A. Field of the invention.

The invention relates to telephone communication systems and, more particularly, to telephone communication systems which utilize discrete multitone modulation to transmit data over digital subscriber lines.

B. Prior art.

The public switched telephone network (PSTN) provides the most widely available form of electronic communication for most individuals and businesses. Because of its

ready availability and the substantial cost of providing alternative facilities, it is increasingly being called upon to accommodate the expanding demands for transmission of substantial amounts of data at high rates. Structured originally to provide voice communication with its consequent narrow bandwidth requirements, the PSTN increasingly relies on digital systems to meet the service demand.

A major limiting factor in the ability to implement high rate digital transmission has been the subscriber loop between the telephone central office (CO) and the premises of the subscriber. This loop most commonly comprises a single pair of twisted wires which are well suited to carrying low-frequency voice communications for which a bandwidth of 0-4 kHz is quite adequate, but which do not readily accommodate broadband communications (i.e., bandwidths on the order of hundreds of kilohertz or more) without adopting new techniques for communication.

One approach to this problem has been the development of discrete multitone digital subscriber line (DMT DSL) technology and its variant, discrete wavelet multitone digital subscriber line (DWMT DSL) technology. These and other forms of discrete multitone digital subscriber line technology (such as ADSL, HDSL, etc.) will commonly be referred to hereinafter generically as "DSL technology" or frequently simply as "DSL". The operation of discrete multitone systems, and their application to DSL technology, is discussed more fully in "Multicarrier Modulation For Data Transmission: An Idea Whose Time Has Come.", IEEE Communications Magazine, May, 1990, pp. 5-14.

In DSL technology, communications over the local subscriber loop between the central office and the subscriber premises is accomplished by modulating the data to be transmitted onto a multiplicity of discrete frequency carriers which are summed together and then transmitted over the subscriber loop. Individually, the carriers form discrete, non-overlapping communication subchannels of limited bandwidth; collectively, they form what is effectively a broadband communications channel. At the receiver end, the carriers are demodulated and the data recovered from them.

The data symbols that are transmitted over each subchannel carry a number of bits that may vary from subchannel to subchannel, dependent on the signal-to-noise ratio (SNR) of the subchannel. The number of bits that can accommodated under specified

communication conditions is known as the "bit allocation" of the subchannel, and is calculated for each subchannel in a known manner as a function of the measured SNR of the subchannel and the bit error rate associated with it.

The SNR of the respective subchannels is determined by transmitting a reference signal over the various subchannels and measuring the SNR's of the received signals. The loading information is typically calculated at the receiving or "local" end of the subscriber line (e.g., at the subscriber premises, in the case of transmission from the central telephone office to the subscriber, and at the central office in the case of transmission from the subscriber premises to the central office) and is communicated to the other (transmitting or "remote") end so that each transmitter-receiver pair in communication with each other uses the same information for communication. The bit allocation information is stored at both ends of the communication pair link for use in defining the number of bits to be used on the respective subchannels in transmitting data to a particular receiver. Other subchannel parameters such as subchannel gains, time and frequency domain equalizer coefficients, and other characteristics may also be stored to aid in defining the subchannel.

Information may, of course, be transmitted in either direction over the subscriber line. For many applications, such as the delivery of video, internet services, etc. to a subscriber, the required bandwidth from central office to subscriber is many times that of the required bandwidth from subscriber to central office. One recently developed service providing such a capability is based on discrete multitone asymmetric digital subscriber line (DMT ADSL) technology. In one form of this service, up to two hundred and fifty six subchannels, each of 4312.5 Hz bandwidth, are devoted to downstream (from central office to subscriber premises) communications, while up to thirty two subchannels, each also of 4312.5 Hz bandwidth, provide upstream (from subscriber premises to central office) communications. Communication is by way of "frames" of data and control information. In a presently-used form of ADSL communications, sixty eight data frames and one synchronization frame form a "superframe" that is repeated throughout the transmission. The data frames carry the data that is to be transmitted; the synchronization or "sync" frame provides a known bit sequence that is used to synchronize the transmitting and receiving modems and that also facilitates determination of transmission subchannel characteristics such as signal-to-noise ratio ("SNR"), among others.

Although such systems do in fact provide a significantly increased bandwidth for data communications, special precautions are required to avoid interference with, and from, ordinary voice communications and associated signaling that may be taking place over the subscriber line at the same time that the broadband data is being carried. The signaling activities commonly include, for example, the transmission of ringing signals, busy tone, off-hook indications, on-hook indications, dialing signals, and the like, and the actions commonly accompanying them, e.g., taking the phone off-hook, replacing it on-hook, dialing, etc. These voice communications and their associated signaling, commonly referred to as "plain old telephone service" or POTS , presently are isolated from the data communications by modulating the data communications onto frequencies that are higher than those used for POTS ; the data communications and POTS signals are thereafter separately retrieved by appropriate demodulation and filtering. The filters which separate the data communications and the POTS are commonly referred to as "POTS splitters".

The voice and data communications must be separated at both the central office and the subscriber premises, and thus POTS splitters must be installed at both locations. Installation at the central office is generally not a significant problem, since a single modem at the central office can serve a large number of subscribers, and technicians are commonly available there. Installation at the customer premises is a problem. Typically, a trained technician must visit the premises of every subscriber who wishes to use this technology in order to perform the requisite installation. In connection with this, extensive rewiring may have to be done, dependent on the desired location of the ADSL devices. This is expensive and discourages the use of DSL technology on a widespread basis.

DSL systems also experience disturbances from other data services on adjacent phone lines (such as ADSL, HDSL, ISDN, or T1 service). These services may commence after the subject ADSL service is already initiated and, since DSL for internet access is envisioned as an always-on service, the effect of these disturbances must be ameliorated by the subject ADSL transceiver.

Summary of the invention

A. Objects of the invention

Accordingly, it is an object of the invention to provide an improved digital subscriber line communication system.

Further, it is an object of the invention to provide a digital subscriber line communication system which is compatible with existing voice communication services and which does not require the use of POTS splitters.

Another object of the invention is to provide an improved digital subscriber line communication system that efficiently handles data communications despite random interruptions associated with concurrent carriage of voice communications or disturbances that arise from concurrent data services on adjacent phone lines.

B. Summary description of the invention.

Splitterless Operation

The invention described herein is directed to enhancing the accuracy and reliability of communications in systems using discrete multitone technology (DMT) to communicate data over digital subscriber lines (DSL) in the presence of voice communications and other disturbances. For simplicity of reference, the apparatus and method of the present invention will hereinafter be referred to collectively simply as a modem. One such modem is typically located at a customer premises such as a home or business and is "downstream" from a central office with which it communicates; the other is typically located at the central office and is "upstream" from the customer premises. Consistent with industry practice, the modems are often referred to herein as "ATU-R" ("ADSL Transceiver Unit, Remote", i.e., located at the customer premises) and "ATU-C" ("ADSL Transceiver Unit, Central Office"). Each modem includes a transmitter section for transmitting data and a receiver section for receiving data, and is of the discrete multitone type, i.e., it transmits data over a multiplicity of subchannels of limited bandwidth. Typically, the upstream or ATU-C modem transmits data to the downstream or ATU-R modem over a first set of subchannels, commonly the higher-frequency subchannels, and receives data from the downstream or ATU-R modem over a second, usually smaller, set of subchanels, commonly the lower-frequency subchannels.

Heretofore, such modems have required POTS splitters when used on lines carrying both voice and data. In accordance with the present invention, we provide a data modem for use in discrete multitone communication systems which carry voice and data communications simultaneously and which operate without the special filtering provided by POTS splitters; they are thus "splitterless" modems. In the absence of certain disturbances, referred to herein as "disturbance events" and discussed more fully hereinafter, the modem of our invention transmits data at a rate determined by the transmission capabilities of the system without regard to such disturbances. Preferably, this is the maximum data rate that can be provided for the particular communications subchannel, subject to predefined constraints such as maximum bit error rate, maximum signal power, etc. that may be imposed by other considerations. On the occurrence of a disturbance event on the communications channel, however, the modem of the present invention detects the event and thereupon modifies the subsequent communication operations. Among other responses, the modem changes the bit allocations (and thus possibly the corresponding bit rate) and the subchannel gains among the subchannels, so as to limit interference with and from voice communication activities or to compensate for disturbances from other services or sources sufficiently close to the subject subscriber line as to couple interfering signals into the line. The bit allocations and subchannel gains may be altered for communications in either direction, i.e., upstream, downstream, or both. Effectively, this matches the subchannel capacity to the selected data rate so as to ensure that the pre-specified bit error rate is not exceeded. On cessation of the disturbance event, the system is returned to its initial, high-rate, state.

Disturbance Events

Of particular interest to the present invention are disturbance events that arise from the occurrence of voice communication activities over the data link concurrent with the transmission of data over the link. These activities comprise the voice communications themselves, or activities such as signaling associated with such communications, together with the response to such activities, such as taking a phone off-hook or placing it on-hook. Disturbance events also include other disruptive disturbances such as interference from adjacent phone lines caused, for example, by the presence of other DSL services, ISDN services, T1 services, etc. The cessation of a disturbance event may itself also

comprise a disturbance event. For example, the change of a voice communications device such as a telephone from "on-hook" to "off-hook" status can seriously disrupt communications at a modem unless compensated for as described herein or unless otherwise isolated from the modem by means of a POTS splitter as was heretofore done; it is thus a disturbance event that must be dealt with. However, the return of such a device to "on-hook" status can also significantly change the channel characteristics and is therefore also a disturbance event that must be dealt with. The invention described herein efficiently addresses these and other disturbance events.

Channel Control Parameter Sets

In accordance with the present invention, the change in bit allocation is accomplished rapidly and efficiently by switching between stored parameter sets which contain one or more channel control parameters that define data communications by the modem over the subchannels. The parameters sets are preferably determined at the time of initialization of the modem and stored in registers or other memory (e.g., RAM or ROM) in the modem itself, but may instead be stored in devices external to, and in communication with, the modem, e.g., in personal computers, on disk drives etc.

In accordance with one embodiment of this invention, the channel control parameter sets comprise at least a primary set of channel control parameters, stored in a primary channel control table, which defines communications in the absence of voice communication activities or other disturbances; and one or a plurality of secondary sets of channel control parameters, stored in a secondary channel control table, that define data communications responsive to one or more disturbance events. When communicating under control of the primary channel control table, the modem is described hereinafter as being in its "primary" state; when communicating under control of the secondary channel control table, the modem is described hereinafter as being in its "secondary" state. The modem is switched between parameter sets in its primary and secondary states responsive to the occurrence and cessation of disturbance events, as well as among parameter sets in the secondary table responsive to a change from one disturbance event to another. Since the parameter sets are pre-stored and thus need not be exchanged at the time of a disturbance event, the switch is made quickly, limited essentially only by the speed with which the disturbance event is detected and signaled to the other modem participating in the com-

munication, typically not more than a second or so. This greatly reduces the interruption in communications that would otherwise be required by a complete reinitialization of the modems that typically extends over six to ten seconds, and its associated exchange channel control parameters.

As noted previously, in DSL communications, information transmission typically takes place in both directions, i.e. the upstream or ATU-C modem transmits downstream to the ATU-R modem over a first set of subchannels, and the downstream or ATU-R modem transmits upstream to the ATU-C modem over a second, different, set of subchannels. The transmitter and receiver at each modem, accordingly, maintain corresponding channel tables to be used by them in transmitting data to, and receiving data from, the other modem with which it forms a communications pair. Certain parameters such as time and frequency domain equalizer coefficients and echo canceller coefficients are "local" to the receiver with which they are associated, and thus need be maintained only at that receiver. Other parameters such as bit allocations and channel gains are shared with the other modem with which a given modem is in communication (the "modem pair") and thus are stored in both modems, so that during a given communication session, the transmitter of one modem will use the same set of values of a shared parameter as the receiver of the other modem, and vice versa.

In particular, in DSL communications, a key parameter is the number of bits that are to be transmitted over the various subchannels. This is known as the "bit allocation" for the respective subchannels, and is a key element of the primary and secondary parameter sets. It is calculated in a known manner for each subchannel based on the channel SNR, the acceptable bit error rate, and the noise margin of the subchannel. Another important element is the gain for each of the subchannels, and is thus preferably also included in the primary and secondary parameter sets. Thus, each receiver stores a primary channel control table and a secondary channel control table, each of which contains one or more parameter sets that define the subchannel bit allocations to be used by it and by the transmitter of the other modem in communicating with it, and each transmitter also stores a primary channel control table and a secondary channel control table, each of which define the subchannel bit allocations and gains to be used by it for transmission to the other receiver and for reception at that receiver. For the closest match to the actual line over

which they are to communicate, those portions of the primary and secondary channel control table at each receiver that define the parameters for use in transmitting to the particular receiver are preferably determined at the modem at which the receiver is located (the "local modem"), as described herein, but it will be understood from the detailed description herein that such tables may also be determined in other ways.

As long as communications over the subscriber line are not impaired by a disturbance event, the modems use the primary channel control table to define communications over the subchannels. When, however, a disturbance event occurs, the modem that detects the event (herein designated "the local modem"; typically, this will be the subscriber modem, ATU-R, particularly in cases of activation of a voice communications device by the subscriber) notifies the other modem of the need to change to the secondary channel control table, and identifies the specific bit allocation set and/or gain set in the secondary table when more than one such set exists. The notification procedure is described in more detail hereinafter. Communications thereafter continue in accordance with the appropriate parameter set (i.e., bit allocations, subchannel gains, and possibly other parameters) from the secondary channel control table. This condition continues until a new disturbance event is detected, at which time the modems revert to the primary channel control table (in the event the disturbance is simply the cessation of communication-disrupting disturbances or interferences) or to a different parameter set secondary channel control table (in the event that the disturbance event is the occurrence of another communication-disrupting disturbance or interference).

In addition to changes in bit allocation among the subchannels, and changes in subchannel gains, further changes may also be made in such communication parameters as time domain equalizer coefficients, frequency domain equalizer coefficients, and the like. These parameters may also be stored in the channel control tables for use in controlling communications, or may be stored in separate tables. Additionally, changes in power level (and corresponding changes in bit allocation and other communication parameters) for communications in either the upstream or the downsteam direction, or both, may be made, and sets of control parameters may be defined on these power levels as well for use in controlling communications. These changes are described in fuller detail below.

As presently contemplated, each modem on the subscribed side of the DSL line will communicate with a corresponding dedicated modem on the central office side. Thus, each central office modem (ATU-C) need store the primary and secondary tables for a specific subscriber only. However, efficiencies may be achieved whenever it is unnecessary to provide service to each subscriber at all times. Under these circumstances, a central office modem may be shared among two or more subscribers, and switched among them as called for. In such a case, the ATU-C will store or have access to a set of channel control tables for each subscriber modem it is to service.

Table Initialization

In the preferred embodiment of the invention, the primary and secondary channel control tables are determined in an initial "training" session ("modem initialization") in which known data is transmitted by one modem, measured on reception by the other, and the tables calculated based on these measurements. Typically, the training session occurs when the modem is first installed at the subscriber premises or at the central office, and the procedure thus "particularizes" the modem to the environment in which it will operate. This environment includes, in addition to the subject data modem, one or more voice communication devices such as telephone handsets, facsimile machines, and other such devices which communicate over a voice frequency subchannel, typically in the range 0-4 kHz. A primary channel control table, comprising a parameter set including at least a set of subchannel bit allocations, and preferably also subchannel gains, is calculated with each device inactive. A secondary channel control table comprising one or more bit communication parameter sets (bit allocations, gains, etc.) is calculated with each voice communication device activated separately, and/or with groups of devices activated concurrently. The tables so determined are then stored at the receiver of one modem and additionally are communicated to the transmitter of the other modem and stored there for use by both modems in subsequent communications.

An alternative approach determines the secondary channel control table (including one or more parameter sets comprising the table) by calculation from the primary channel control table. This is accomplished most simply, for example, by taking one or more of the parameters (e.g., the bit allocation parameter which defines the number of bits to be used for communication across the respective subchannels) as a percentage, fixed or

varying across the subchannels, of the corresponding primary parameters; or as determined in accordance with a percentage, fixed or varying across the subchannels, of the SNR's of the respective subchannels; or as determined in accordance with a different bit error rate than provided for in the primary channel control table; or by other techniques.

As a specific example, a number of different sets of bit allocations in the secondary channel control table may be determined as differing percentages (fixed or varying across the subchannels) of the corresponding set of bit allocations in the primary channel control table. Each secondary bit allocation set corresponds to the effect commonly produced by a particular device or class of devices, e.g., a telephone handset, a facsimile machine, etc., as determined by repeated measurements on such devices, and thus may be taken to represent the expected effect of that device over a range of communication conditions, e.g., with a particular type of subscriber line wiring, at a given range from the central office, etc. The subchannel gains may also then be adjusted based on the redetermined bit allocations. The bit allocations and subchannel gains so determined form new secondary parameter sets which may be used responsive to detection of the disturbance events they characterize, and which substitute for determination of the secondary bit allocations and gains on the basis of measurements of the actual disturbances being compensated for.

Alternatively, the secondary channel control table may be determined by adding a power margin to the calculations for each of the entries of the primary table of a magnitude sufficient to accommodate the interference from activation of the voice communications device or from other disturbances. This has the effect of reducing the constellation size for the table entries. The margin may be uniform across the table entries, or may vary across them, as may the percentage factor when that approach is used. Multiple secondary bit allocation sets may be defined by this approach, each based on a different power margin.

One example of the use of varying margins is in response to changes in crosstalk (capacitively coupled noise due to nearby xDSL users, where the "x" indicates the possible varieties of DSL such as ADSL, HDSL, etc.). This crosstalk is, in general, more predictable than signaling events associated with voice communications. The crosstalk spectrum of xDSL sources is well characterized: see, for example, the T1.413 ADSL standard published by the American National Standards Institute. From a primary channel control

table associated with a single full initialization, a secondary table comprising a family of bit allocation sets can be calculated, each corresponding to a different crosstalk level. As the number of xDSL systems (and thus crosstalk levels) changes, the ADSL link can quickly switch to one of these automatically generated sets.

The secondary channel control table in the present invention may also be adapted dynamically, e.g., by performing measurements on the transmitted information in each superframe during data communications and monitoring these measurements to determine when the channel performance has sufficiently changed that a different bit allocation set, and possibly different gain set, should be used. We have found that the SNR provides a readily measurable and reliable indicator of the required bit allocations and gains.

In particular, we have found that measurements of the SNR levels across a number of the subchannels during a given communications condition or state provides a "fingerprint" which may reliably be used to quickly select a parameter set, such as the set of bit allocations or the set of gains, for use in subsequent communications during that state. These measurements may be made, for example, on the sync frame that occurs in each superframe or, more generally, during the transmission of reference frames. When the SNR's change by more than a defined amount during communications, the modem at which the measurement is made searches the stored parameter sets for a set whose SNRs on the corresponding subchannels is closest to the measured SNRs, and selects that set for use in subsequent communications. If no parameter set is found within defined limits, the system may be switched to a default state, or a complete reinitialization may be called for, corresponding to a defined pattern of SNR's across some or all of the subchannels, should be used. SNR measurements may also be made on the data carrying signals themselves, i.e., a decision-directed SNR measurement.

Instead of using a multiplicity of secondary subchannel control parameter sets as described above, a simplified approach may construct and use a single secondary set based on a composite of the bit allocation or other characteristics of the individual devices. In one embodiment, the composite is formed by selecting, for each subchannel, the minimum bit allocation exhibited by any device for that subchannel, or the most severe characteristic of any other disturbances, thus forming a single "worst case" set that may be used when any device is activated, regardless of the specific device or disturbance ac-

tually present. Or it may be determined as the actual or calculated capacity of the line when all devices are actually or theoretically actuated simultaneously, or all disturbances are present, or both concurrently. Bit allocations sets may also be determined for combinations of subsets of such devices and disturbances. A similar approach may be used to handle the situation where several devices are activated at the same time, and the effects of other disturbances such as cross talk, etc. may also be incorporated into a composite set.

A particular parameter set of the secondary channel control table remains in use for the duration of the session in which the voice device is active or until another change of state occurs, e.g., a further voice device is activated or some other disturbance takes place. When this occurs, the local modem renews its identification procedure to enable determination of the appropriate parameter set for the new conditions. At the end of the session in which the voice device is active, the device returns to inactive (i.e., "on-hook") status and the system reverts to its original ("on-hook") status in which the primary channel control table once again is used for communications between the central office and the subscriber.

Switching the subchannel parameter sets in accordance with the present invention is extremely fast. It can be accomplished in an interval as short as several frames, and thus avoids the lengthy (e.g., several second) delay that would otherwise accompany determination, communication, and switching of newly-determined sets. Further, it avoids communicating new parameter sets at a time when communications have been impaired and error rates are high. Thus, it minimizes disruption to the communication process occasioned by disturbance events.

Detecting Disturbance Events

During subsequent data communications, identification of the device that is activated is achieved in one of a number of ways. In one embodiment of the invention, a specific activation signal is transmitted from the device to the modem on the same side of the subscriber line as the device (referred to herein as "the local modem") on activation of the device. This signal may be transmitted over the communications line to which the device and the local modem are connected or it may be sent over a dedicated connection

between the device and the local modem.

In the preferred embodiment of the invention, the local modem monitors the subscriber line to which it and the device are connected and detects a change in line characteristics when the device is activated. For example, the signal to noise ratio (SNR) of the various subchannels can quickly be measured and can be used to identify the particular device that is activated. During multiple sets of initializations, corresponding to multiple communication conditions caused by the devices or by other interferences, the SNR measure for each subchannel is determined for each of the conditions to be tracked (i.e., no devices activated, devices activated separately, two or more devices activated concurrently, adjacent channel interference, etc.) and the measures stored, along with identification of the particular parameter set or sets with which they are associated. When a device is activated, the SNR measurements are used to quickly identify the particular device or devices that have been activated, and the local modem can thereafter switch to the appropriate secondary table.

Disturbance events may also be detected in accordance with the present invention by monitoring selected transmission characteristics that are dependent on these events. These may comprise, in addition to any characteristic SNR accompanying them, such measures as errors in the cyclic redundancy code (CRC) that accompanies transmissions and changes in the error rate of this code; changes in the amplitude, frequency or phase of a pilot tone on the subchannels; or other such indicia. Forward error correction code (FEC) is typically used in ADSL transceivers, and changes in the error rate characteristics of this code, such as how many errors have occurred, how many have been corrected, how many are uncorrected, and the like, can be particularly useful in detecting disturbance events.

In monitoring these characteristics, we distinguish between changes caused by momentary or transient events such as lightning or other such burst noise disturbances, and those associated with disturbance events, the latter continuing for a significant interval (e.g., on the order of seconds or more). In particular, in embodiments that monitor CRC errors or error rates in accordance with the present invention, a switch from one parameter set to another is provided when the errors extend over a number of frames or when the error rate changes by a defined amount for a time greater than a defined mini-

mum. For example, on the occurrence of an off-hook event , a severe form of disturbance to data communications over a subscriber loop, the number of CRC errors suddenly increases and remains at an increased level until it is dealt with. This is distinguished from the occurrence of a transient disturbance such as a lightning strike which causes a momentary increase in CRC errors that does not persist as long as the system has not lost synchronization.

Thus, in accordance with the present invention, the detection of an initial change in the CRC error rate over a number of frames in excess of a defined threshold is one example of the detection of a disturbance event that will result in switching parameter sets. Similar procedures may be undertaken in response to measurement of the signal-to-noise ratio of the subchannel in order to detect a disturbance event based on this characteristic. The decision as to whether a disturbance event has occurred may be based on measurements on a single subchannel; on a multiplicity of subchannels (e.g., the decision to switch parameter sets will be made when more than a defined number of subchannels detect a disturbance event); or the like.

An alternative technique for detecting a disturbance event in accordance with the present invention is the use of a monitor signal, e.g., a pilot tone whose amplitude, frequency, phase or other characteristic is monitored during data transmission. A sudden change in one or more of the monitored characteristics from one frame to another, followed by a smaller or no change in subsequent frames, indicates a disturbance event to which the modem should respond. The monitor signal may comprise a dedicated signal carried by one of the subchannels; a signal carried on a separate control subchannel; a disturbance event itself (e.g., ringing tone, dial tone presence, or other common telephone signals); or other signals.

Communicating The Occurrence of Disturbance Events

After a disturbance event is detected and the appropriate parameter set corresponding to the event is identified, the identification is communicated to the remote modem by means of a selection signal to enable it also to switch to the corresponding parameter set in the secondary table. The selection signal may be in the form of a message transmitted over one or more subchannels or using a predetermined protocol for an em-

bedded operations channel, or it may comprise one or more tones that identify the particular parameter set. ADSL systems use a "guard band" of several subchannels between the sets of subchannels used for upstream and downstream transmission. This guard band may be used to transmit the selection tone or tones. In cases where there is only a single parameter set to be designated, the selection signal may comprise a simple flag (an element that has only two states, i.e., on/off, present/absent, etc.) that is sent to the remote modem to select the set.

In a further embodiment of the invention, use is made of the frame counters at the ATU-R and ATU-C modems that are commonly provided in DSL systems. On detecting a disturbance event, the ATU-R modem notifies the ATU-C modem of the event and specifies a frame at which the change in parameter set, or change in power level and any accompanying change in other parameters, is to take place. The specification may be direct (i.e., the notification specifies a particular frame number at which the change to the secondary table is to be made) or indirect (i.e., on receipt of the notification, the change to the secondary table is made at one of a predetermined number of frames, e.g., the next frame number ending in "0", or in "00", etc., or the nth frame after receiving the notification, where n is some number greater than 0). On reaching the designated frame, both modems (i.e., ATU-R and ATU-C) switch to the new bit allocation set, power level, and other designated parameters.

Alternatively, on detection of a disturbance event, the modems perform a "fast retrain" in order to characterize communications under the new operating conditions and determine a power and/or bit allocation set to be used for the communications. A fast retrain performs only a limited subset of the full initialization procedures, e.g., bit allocation and subchannel gain determination,. The retraining modem (typically the modem local to the disturbance initiating the retraining) then compares the newly determined parameter set with previously stored sets. If the newly-determined set is the same as a previously stored set, a message, flag, or tone is communicated by one modem to the other to designate which of the stored secondary allocation sets is to be used. Otherwise, the newly determined set is used for communications. In the latter event, it must be communicated to the other modem in the communication pair, and communications may be interrupted while this occurs. Nonetheless, on cessation of the event which necessitated a

change in parameter sets, the system may simply revert to the primary parameter set, without need for recommunication of that set and thus without further interrupting communications. With proper care in initialization, in most cases a sufficient array of parameter sets may be defined and exchanged at the outset as to avoid the need for subsequent reinitialization in response to most disturbances.

Changing Power Levels

In addition to changing one or more parameter sets in the modem in response to a disturbance event, in accordance with the preferred embodiment of the present invention we also preferably change the communications power level in either the upstream or the downstream direction, or both, in order to further enhance reliable communications. Typically, the change is a reduction in the power level in the upstream direction so as to minimize interference with the voice communications, as well as to reduce echo into the downstream signal, and it will be so described herein. However, it should be understood that there will be some occasions when an increase in power level is called for, such as when interference from adjacent data services requires a higher power level in order to maintain a desired data rate or bit error level, and such a change is accommodated by the present invention in the same manner as that of a decrease. Further, a change in downstream power level may be called for when line conditions change to such an extent that excessive power would otherwise be fed into the downstream channel from the upstream modem

In theory, and in a perfectly linear system, upstream communications activities should have no effect on concurrent voice communications since the two activities occur in separate, non-overlapping frequency bands. However, the telephone system in fact is not a linear system, and nonlinearities in the system can and do inject image signals from the upstream subchannel into the voice subchannel, and possibly into the downstream subchannel as well (i.e., echo), thus producing detectable interference. In accordance with another aspect of the present invention, this effect is reduced below the level of objection by reducing the upstream power level (the power level at which the subscriber or downstream modem transmits to the central office or upstream modem) by a given amount or factor when conditions dictate, e.g., when a voice communications device is off-hook and leakage from the data communications being conducted interferes with the

voice communications.

The amount of power reduction may be set in advance. For example, we have found that a nine db reduction in this power (relative to that typically used in ADSL applications using splitters to separate the data and POTS signals) is sufficient in most cases of common interest; under these circumstances, the system operates in one of two alternative power levels at all times. Alternatively, the downstream modem may select one of several different power levels for use, based on the communication conditions prevailing at the time resultant from the disturbance event. For example, the downstream modem may be activated to send a test signal into one or more upstream subchannels and to monitor the leakage (i.e., the echo) of this signal into one or more downstream subchannels as determined, for example, by the SNRs on these subchannels; the power level at which the downstream modem transmits upstream may then be adjusted accordingly in order to minimize the effects of the echo. Commonly, the downstream transmit power is determined by the ATU-R, since the ATU-R is closest to the cause of the disturbance event. In this event, the ATU-R uses a message, flag, or tone to inform the ATU-C of the desired power level to be used for transmission. In either case, at the end of a session, the power level reverts to that used in the "on-hook" state.

In selecting the desired power level, the transmitting modem signals the receiving modem in the communications-pair of the desired change (including the designation of a particular power level from among several power levels, where appropriate), and thereafter implements the change, including switching to a new parameter set associated with that power level. In another embodiment of the invention, the receiving modem detects the power level change at the transmitting modem and switches to a parameter set associated with that power level; upstream communications (i.e., from the ATU-R to the ATU-C) are thereafter conducted at the new power level until the disturbance event (e.g., off-hook condition, etc.) terminates.

While much of the above has been described in terms of a change in power level in the upstream communications from the subscriber modem to the central office modem, it should be noted that a change in power level in the opposite direction may also sometimes be called for. This may be the case, for example, on short subscriber loops (e.g., less than a mile), where the reduced line loss consequent on the greater proximity to the central

office may result in the central office initially transmitting at an excessive power level. In such cases, the central office or ATU-C modem performs the role previously performed by the subscriber or ATU-R modem, and vice versa, and a change in power level and other parameters on the downstream communications may be performed as described above. Further, it should also be understood that while it is expected that the power change will most commonly be one that reduces the power level used to communicate, it may in some cases increase it. This will occur, for example, when crosstalk from adjacent services requires an increase in power level of the subject service in order to compensate for the crosstalk.

Changing Other Parameters

A further important change made in response to detecting a disturbance event is a change in the frequency domain equalizers ("FDQ's") associated with each subchannel. These equalizers compensate for the differing distortions (e.g., amplitude loss, phase delay, etc.) suffered by the data during transmission over the subchannel. Typically, they comprise finite impulse response filters with complex coefficients. The coefficients are set during the "initialization" or "training" phase of modem setup. They may subsequently be adjusted based on reference (known) data in reference frames or sync frames transmitted over the communication subchannel. In accordance with the present invention, these filters are adjusted responsive to the transmitted reference data when a disturbance event is detected. The coefficient updating may be performed on all subchannels, or selectively on those whose change in error rates, signal-to-noise ratios, or other error indicia, indicate a disturbance event.

In accordance with one embodiment of the present invention, the coefficients of the frequency domain equalizers for communications both in the absence of a disturbance event or disturbance ("primary FDQ coefficients") and in the presence of such an event or disturbance ("secondary FDQ coefficients") are computed and stored during the initialization or training period. Thereafter, these coefficients are switched responsive to a disturbance event, as is the case with the channel control tables, and are returned to an initial state on the cessation of such an event.

In accordance with another embodiment of the invention, the FDQ coefficients are

recomputed responsive to detection of a disturbance event and then used throughout the remainder of the communications session in place of the earlier-stored secondary FDQ tables. The recomputation is accomplished in a short "retrain" session in which known reference data is transmitted between the ATU-R and ATU-C . The received data is compared with the known data and the new FDQ coefficients are determined accordingly. In addition to the frequency domain equalizer coefficients, time domain equalizer coefficients and echo cancellation coefficients may also be determined and stored. Such coefficients are local to the particular receiver, and thus need not be communicated to the other modem of the communications pair. Accordingly, any such retrain will be extremely fast, and any consequent disruption to communication limited.

Excessive Disturbances

In some cases a particular device may cause such interference with communications that compensation for that device by the methods described herein is not practical. This may occur, for example, with antiquated telephones or with particularly complex in-home wiring. In such a case, it is desirable to minimize the disruption caused by such a device by inserting a simple in-line filter between the device and the subscriber line. The filter may comprise, for example, a simple low-pass filter of not more than a cubic inch in volume and a pair of standard connectors such as RJ11 connectors through which the filter connects to the device on one side and to the subscriber line on the other. Unlike POTS splitters, such a connector needs no trained technician to install it, and thus presents no barrier, cost or otherwise, to acceptance of ADSL modems as described herein. Such a device may be detected by measuring the nonlinear distortion of the device when it is activated. This is done by monitoring the echo on the line caused by that device.

Reduced Rate Communications

A further improvement in the operation of the modem of the present invention resides in confining the bandwidth of the downstream transmission to a subset of that normally provided in ADSL communications. This reduces the processing demands on both the local (i.e., central office) and remote (subscriber premises) modems, thereby facilitating the provision of subscriber premises modems at prices more acceptable to consumer, non-business, use; additionally, it further minimizes interference between data transmis-

sion and voice communications. For example, limiting the number of subchannels used by the modem to one hundred and twenty eight as opposed to two hundred and fifty six reduces the downstream bandwidth from 1.1 MHz to approximately 552 kHz. When the modem is used with modems that normally provide a greater number of subchannels for such communications, the bit allocations and gains for the subchannels above one hundred and twenty eight are preferably nulled, i.e., set to zero.

The invention is preferably operable with modems that do not have the capabilities described herein, as well, of course, with modems that do. Accordingly, the modem of the present invention identifies its capabilities, preferably during initialization, preparatory to data exchange with another modem. In accordance with the preferred embodiment of the invention, this is preferably done by signaling between the modems that are to participate in communications. The signaling identifies the type of modems in communication and their characteristics of significance to the communication session. For example, one form of ADSL transceiver uses a reduced number of subchannels (typically, thirty two subchannels upstream and one hundred twenty eight subchannels downstream) and provides lower bandwidth communications. A modem having full ADSL capabilities that encounters a reduced-rate modem can then adjust its transmission and reception parameters to match the reduced-rate modem. This may be done, for example, by transmission from one modem to the other of a tone that is reserved for such purposes.

In particular, in accordance with the present invention, on initiation of communications between a central office modem and a subscriber premises modem, the modems identify themselves as “full rate” (i.e., communicating over two hundred and fifty six subchannels) or “reduced rate” (e.g., communicating over some lesser number of subchannels, e.g., one hundred and twenty eight). The communication may be performed via a flag (two-state, e.g., “on/off”, “present/absent”), a tone or tones, a message (n-state, n>2), or other form of communication, and may be initiated at either end of the communication subchannel, i.e., either the central office end or the customer premises end.

Brief description of the drawings

The invention description below refers to the accompanying drawings, of which:

Figure 1 is a block and line diagram of a conventional digital subscriber line

(DSL) system using POTS splitters that is characteristic of the prior art;

Figure 2 illustrates an illustrative bit allocation and gains table used in the apparatus of Figure 1;

Figure 3 is a block and line diagram of a splitterless DSL system in accordance with the present invention;

Figure 4 is a block diagram of a splitterless transceiver in accordance with the present invention;

Figures 5A-5C illustrates channel control tables constructed and used in accordance with the present invention;

Figure 6 is a diagram of one form of disturbance event detector in accordance with the present invention;

Figure 7 illustrates the use of a frame counter for communicating the switching decision to the remote modem;

Figure 8 illustrates the preferred procedure used for performing a fast retrain of the modems in accordance with the present invention;

Figure 9 illustrates the manner in which channel control tables may readily be selected in accordance with the present invention; and

Figure 10 illustrates alternative configuration for interconnection of the modems of the present invention.

Detailed description of an illustrative embodiment

Figure 1 shows an ADSL communications system of the type heretofore used incorporating "splitters" to separate voice and data communications transmitted over a telephone line. As there shown, a telephone central office ("CO") 10 is connected to a remote subscriber 12 ("CP: Customer Premises") by a subscriber line or loop 14. Typically, the subscriber line 14 comprises a pair of twisted copper wires; this has been the traditional medium for carrying voice communications between a telephone subscriber or customer and the central office. Designed to carry voice communications in a bandwidth of approximately 4 kHz (kilohertz), its use has been greatly extended by DSL technology.

The central office is, in turn, connected to a digital data network ("DDN") 16 for sending and receiving digital data, as well as to a public switched telephone network ("PSTN") 18 for sending and receiving voice and other low frequency communications. The digital data network is connected to the central office through a digital subscriber line access multiplexer ("DSLAM") 20, while the switched telephone network is connected to the central office through a local switch bank 22. The DSLAM 20 (or its equivalent, such as a data enabled switch line card) connects to a POTS "splitter" 24 through an ADSL transceiver unit -central office ("ATU-C") 26. The local switch 20 also connects to the splitter.

The splitter 24 separates data and voice ("POTS") signals received from the line 14. At the subscriber end of line 14, a splitter 30 performs the same function. In particular, the splitter 30 passes the POTS signals from line 14 to the appropriate devices such as telephone handsets 31, 32, and passes the digital data signals to an ADSL transceiver unit-subscriber ("ATU-R") 34 for application to data utilization devices such as a personal computer ("PC") 36 and the like. The transceiver 34 may advantageously be incorporated as a card in the PC itself; similarly, the transceiver 26 is commonly implemented as a line card in the multiplexer 20.

In this approach, a communication channel of a given bandwidth is divided into a multiplicity of subchannels, each a fraction of the subchannel bandwidth. Data to be transmitted from one transceiver to another is modulated onto each subchannel in accordance with the information-carrying capacity of the particular subchannel. Because of differing signal-to-noise ("SNR") characteristics of the subchannels, the amount of data loaded onto a subchannel may differ from subchannel to subchannel. Accordingly, a "bit allocation table" (shown as table 40 at transceiver 26 and table 42 at transceiver 34) is maintained at each transceiver to define the number of bits that each will transmit on each subchannel to the receiver to which it is connected. These tables are created during an initialization process in which test signals are transmitted by each transceiver to the other and the signals received at the respective transceivers are measured in order to determine the maximum number of bits that can be transmitted from one transceiver to the other on the particular line. The bit allocation table determined by a particular transceiver is then transmitted over the digital subscriber line 14 to the other transceiver for use by the other

transceiver in transmitting data to that particular transceiver or to any similar transceiver connected to the line 14. The transmission must, of course, be done at a time when the line is not subject to disturbances which may interfere with communications. This is a significant limitation, and restricts the utilization of this approach.

Referring now to figure 2, a bit allocation table 42 such as is used in the customer premises equipment is shown in further detail. Table 40, used at the central office, is essentially the same in construction and operation and will not further be described. Table 42 has two sections, a first section, 42a, which defines certain communication parameters such as bit allocation capacity and subchannel gain parameters that characterize the respective subchannels and which the transmitter section of transceiver 34 will use in transmitting a signal to the other transceiver (26) with which it is in communication; and a section 42b that defines the parameters that the receiver section of transceiver 34 will use in receiving a signal transmitted from the other transceiver. Communications take place over a plurality of subchannels, here shown, for purposes of illustration only, as subchannels "9", "10", etc. in the transmitter section, and subchannels "40", "41", etc. in the receiver section. In a full-rate ADSL system, there are up to two hundred and fifty six such subchannels, each of bandwidth 4.1 kHz. For example, in one embodiment of the inventin, upstream communications (i.e., from the customer premises to the central telephone office) are conducted on subchannels 8 to 29; downstream communications (from the central office to the customer premises) are conducted on subchannels 32 to 255; subchannels 30 and 31 form a guard band between upstream and downstream communications that may be used for signaling as described hereinafter.

For each subchannel ("SC") 50, a field 52 defines the number of bits ("B") that are to be transmitted over that subchannel by the transmitter of a communications or modem pair, and received by the receiver of that pair, consistent with the prevailing conditions on the subchannel, e.g., measured signal-to-noise ratio (SNR), desired error rate, etc.; column 54 defines the corresponding gains ("G") of the subchannels. A first section, 42a, of the table specifies the bit allocations and gains that transceiver 34 will use in transmitting "upstream" to the transceiver 26; and a second section, 42b, specifies the bit allocations and gains that transceiver 34 will use in receiving transmissions from the transceiver 26. Transceiver 26 has a corresponding table 40 which is the mirror image of table 42, that is,

the bit allocations specified for transmission by transceiver 34 are the same as those specified for reception by transceiver 26 and correspondingly for reception by transceiver 34 and transmission by transceiver 26. The table typically may also include a field specifying the gain 54 associated with the particular subchannel.

As noted above, the splitters 24, 30 combine the data and voice communications applied to them for transmission and once again separate these from each other on reception. This is accomplished by means of high pass and low pass filters which separate the low-frequency voice communications from the high-frequency data. The need to utilize such splitters, however, imposes a severe impediment to the widespread adoption of DSL technology by the consumer. In particular, the installation of a splitter at the subscriber premises requires a trip to the premises by a trained technician. This can be quite costly, and will deter many, if not most, consumers from taking advantage of this technology. Nor is incorporating splitters in the communications devices themselves a viable option, since this not only increases the cost of such devices, but requires either the purchase of all new devices or the retrofit of the older devices, which again requires skilled help to accomplish. In accordance with the present invention, we eliminate the splitter at least at the customer premises, thereby enabling adoption and use of DSL modems by the end user without the intervention of trained technical personnel. This, however, requires significant changes in the structure and operation of the DSL transceivers or modems, and the present invention addresses these changes.

In particular, figure 3 shows a DSL transmission system in accordance with the invention in which the composite voice-data signal transmitted from the central office to the subscriber premises is passed to both the subscriber voice equipment 31, 32 and to the data transceiver or modem 34' without the interposition of a splitter at the subscriber premises. In figure 3, components that are unchanged from figure 1 retain the same numbering; components that are modified are designated with a prime superscript. In place of the single table 30 of the transceiver 26 of Figure 1, the transceiver 26' of Figure 3 contains a primary channel control table 41 and a secondary channel control table 43. Similarly, transceiver 34' of Figure 3 contains a primary channel control table 45 and a secondary channel control table 47. It will also be noted that the subscriber side splitter has been eliminated in Figure 3: the reason why this can be done in the present invention

will now be described in detail. It will also be noted that the central office splitter 20 in figure 1 has been retained in the configuration of Figure 3: this is optional, not mandatory. Retaining a splitter at the central office can improve the performance somewhat at little cost, since only a single installation is required and that at the central office itself where technical personnel are commonly available in any event. Where this is not the case, it may be eliminated there also.

Turning now to figure 4, the transceiver or modem 34' is shown in greater detail; the modem 26' is essentially the same for present purposes and will not be separately described. As indicated, modem 34' comprises a transmitter module 50; a receiver module 52; a control module 54; a primary channel control table 45; and a secondary channel control table 47. The primary channel control table is shown more fully in figure 5A.; the secondary channel control table is shown more fully in figure 5B.

In figure 5A, the primary channel control table 45 has a transmitter section 45a which stores a primary set of channel control parameters for use in transmitting to a remote receiver over a DSL line; and a receiver section 45b which stores a primary set of channel control parameters for use in receiving communications over a DSL line from a remote transmitter. The subchannels to which the parameters apply are shown in column 45 c. The channel control parameters in the transmitter section 45a include at least a specification of the bit allocations ("B") 45d and preferably also the gains ("G") 45e to be used on the respective subchannels during transmission. The receiver section similarly includes specification of the bit allocations and gains, and preferably also includes specification of the frequency domain equalizer coefficients ("FDQ") 45f, time domain equalizer coefficients ("TDEQ") 45g, and echo canceller coefficients ("FEC") 45h, among others.

Collectively, the parameters: bit allocation, gain, frequency domain coefficient, time domain coefficient, etc. form a parameter set, each of whose members are also sets, e.g. the bit allocation set defining the allocation of bits to each of the subchannels, the gain setting set defining the gains across the subchannels, etc. In accordance with the preferred embodiment of the present invention, the primary channel control table stores a single parameter set which has at least one member, i.e., a bit allocation set, and preferably a gain allocation set as well; this parameter set defines the default communications conditions to which the system will revert in the absence of disturbance events. The sec-

ondary channel control table, however, has at least two, and typically more, parameter sets for controlling transmission and reception over the subscriber lines by the respective modems; these sets define communications under various disturbance events which change the default conditions.

In particular, in Figure 5B, the secondary channel control table 47 comprises a plurality of parameter sets 47a, 47b, 47c, etc., of which only three sets are shown for purposes of illustration. Each parameter set includes a transmit portion 47 d and a receive portion 47e. In each portion, one or more parameters are specified, e.g., bit allocations 47f and gains 47g in the transmit portion 47d, and frequency domain coefficients 47h, time domain coefficients 47i, and echo cancellation coefficients 47j in the receive portion 47e. The actual values of the coefficients are typically complex numbers and thus they are represented simply by letters, e.g., "a", "b", etc. in the channel control tables of Figures 5A and 5B. Parameter sets 47b, 47c, and the remaining parameter sets are similarly constructed. As was the case for the primary channel control table, each parameter (e.g., bit allocation) is itself a set of elements that define communication conditions, at least in part, across the subchannels to which they apply and which they help characterize.

The primary channel control table containing a bit allocation parameter set is generated in the usual manner, i.e., during initialization (typically, a period preceding the transmission of "working data" as opposed to test data), known data is transmitted to, and received from, the remote modem with which the instant modem is in communication under the conditions which are to comprise the default condition for the modem. Typically, this will be with all disturbing devices inactivated, so that the highest data rate can be achieved, but the actual conditions will be selected by the user. The data received at each modem is checked against the data known to have been transmitted and the primary channel control parameters such as bit allocation, subchannel gains, and the like are calculated accordingly. This table is thereafter used as long as the system remains undisturbed by disturbance events which disrupt communications over the line.

The secondary channel control table may be determined during initialization in the same manner as the primary table, but with devices that may cause disturbance events actuated in order to redetermine the channel control parameters required for communications under the new conditions. These devices may be actuated one by one, and a secon-

dary parameter control set determined for each and stored in the secondary channel control table; or they may be actuated in groups of two or more, and parameter sets determined accordingly; or various combinations of single and group actuations may be performed and the corresponding parameter sets determined. Secondary parameter sets may similarly be determined from actual measurements with interfering sources such as xDSL transmissions in a common binder with the modems in question, and the resultant sets stored in the secondary table.

Other methods of determination of the secondary table may be employed. For example, one or more secondary parameter sets may be derived from the primary table. Thus, the bit allocation on each subchannel in the secondary table may be taken as a percentage, fixed or varying across the subchannels, of the bit allocation for each subchannel defined in the primary table. Alternatively, it may be calculated from the same data as that of the primary table, but using a larger margin; by using a percentage, fixed or varying across the subchannels, of the signal-to-noise ratio used in calculating the primary table; by providing for a different bit error rate than provided for in the primary; or by other techniques, including those described earlier. Portions of the primary and secondary may be recalculated or improved upon during the communication session, and stored for subsequent use. The calculation or recalculation may be a one-time event or may occur repeatedly, including periodically, throughout a communication session.

Further, although use of a multiplicity of parameter sets in the secondary channel control table will generally provide the best match to the actual channel conditions and thus more nearly approach optimum communications conditions, a simplified second table containing a single composite parameter set may also be used. Thus Figure 5C shows a number of sets 49a-49d of bit allocations for the subchannels 49e and which may represent a corresponding number of different communication devices or conditions associated with communications over these subchannels. A single composite parameter set 49f may be formed as a function of the parameter sets 49a-49d by, for example, selecting, for each subchannel, the minimum bit allocation among the sets 49a-49d for each of the subchannels 49e. Such a set represents a "worst case" condition for activation of any of the devices associated with the sets 49a-49d. Other worst case parameter sets may be formed, for example, on selected groups of devices, thus providing for the case when several de-

vices or disturbances are operating simultaneously.

In the absence of a disturbance event, the transceivers 26', 34' use the primary channel control tables 41, 45 for communications. Responsive to detection of a disturbance event, however, the transceivers 26', 34' switch to one of the parameter sets of the secondary channel control tables 43, 47 to continue the communications under the conditions specified by the particular parameter table. These conditions may specify a diminished bit rate while maintaining the same bit error rate as is provided with the primary channel control table; or may specify the same bit rate but at a higher bit error rate; or may specify a diminished bit rate at a correspondingly diminished power level or margin; or other conditions as determined by the specific channel control tables. On termination of the disturbance condition which caused the switch, the transceivers 26', 34' return to use of the primary tables 41, 45.

Typically, the primary tables provide communications at or near the capacity of the communications channel over line 14. The secondary tables provide communications over the channel at a diminished rate. Switching between the primary and secondary tables (that is, switching from a primary parameter set to a secondary parameter set) in accordance with the present invention is fast: it can be accomplished in an interval as short as several frames (each frame being approximately 250 microseconds in current ADSL systems), and thus avoids the lengthy delay (e.g., on the order of several seconds) that would otherwise be required for determination, communication over the subscriber line, and switching of newly-determined bit allocation tables. Further, it avoids communication of such tables over the subscriber line at a time when communications have been impaired and error rates are therefore high. Thus, utilization of prestored parameter sets in accordance with the present invention minimizes disruption to the communication process occasioned by disturbance events.

The channel control tables are stored in a storage or memory for rapid access and retrieval. Preferably, the storage is a random access memory ("RAM") incorporated into the modem itself, but also comprise such a memory located in other components accessible to the modem, e.g., in a stand-alone memory; in a computer such as a personal computer ("PC"); in a disk drive; or in other elements. Further, the storage may include portions of other forms of memory, such as read only memory ("ROM").

In addition to accessing the channel control tables 45 and 47, the control module 54 of Figure 4 preferably also controls formulation of the secondary control table when this table is calculated on the basis of the primary channel control table. Further, the module 54 monitors the SNR on the subscriber line 14 and calculates the primary and secondary channel control parameter sets when these sets are based on measurement of actual conditions of the line, as will most commonly be the case. To this end, the control module is advantageously implemented as a special purpose digital computer or "DSP" chip particularized to the functions described herein. It may, of course, alternatively be implemented as a general purpose computer or in other fashion, as will be understood by those skilled in the art.

In accordance with the present invention, disturbance events on the subscriber line are distinguished from transient events such as lightning impulses by mean of their consequences. In particular, a signaling event such as an off-hook signal or an on-hook signal typically causes sufficient disruption as to preclude further communications without re-initialization. The event is accompanied by an error code indication that persists throughout the disruption; a change in the amplitude and phase of the physical signal carrying the data or of a pilot tone; the application of a substantial voltage to the line; and other indicia. We monitor the subscriber line for the occurrence of one of more of these characteristics in order to detect the event.

Figure 6 illustrates one manner of detecting a disturbance event in accordance with the present invention. A detector 70, which is preferably included in control module 54, receives signals from line 14 and monitors (step 72) the error code (e.g., CRC errors or the FEC error count) associated with the signals for occurrence of an error indication. If no error is detected (step 74), the detector remains in monitoring mode without further action. If an error is indicated by the error code, a counter is incremented (step 76) and the count is then compared with a predefined threshold (step 78). If the count does not exceed the threshold (step 78, ">N?"), the system remains in monitoring mode and continues to accumulate any detected errors. If the count exceeds the threshold (step 78, Y), the detector emits a "disturbance event" detection signal (step 80) which causes the transceiver in which the detector 70 is located to initiate the process of switching to the appropriate parameter set in the secondary table. The count is reset (line 81) when this occurs.

Instead of monitoring the error code for characteristic behavior (i.e., repeated error over successive frames), in accordance with the present invention one may monitor the amplitude and phase of the physical signals transmitting the data over the subchannel or of a pilot tone transmitted between modems. On the occurrence of a disturbance event, the amplitude and phase of the physical signal undergo significant change, i.e., the amplitude suddenly decreases and the phase suddenly shifts to a new value; thereafter, they maintain approximately their new values during successive frames. This behavior may be monitored as shown in Figure 7 in which a monitor 100 monitors, for example, the amplitude of a data signal or a pilot tone on line 14 and sets a flip-flop 102 to an "active" state ("Q") on detecting a change in the amplitude of greater than a predefined threshold value. Flip-flop 102 enables (input "E") a counter 104 connected to receive counting pulses from a frame counter 106 whenever a new frame is transmitted or received by the modem. These counting pulses are also applied to a threshold counter 108 which accumulates the counts applied to it until it reaches a defined count and then applies the resultant count to a comparator 110 where it is compared with the count in counter 104. If the contents of the counters 104 and 108 are equal, comparator 110 provides an output ("Y") which causes the transceiver to initiate the process of switching to the appropriate table. This also resets the counters 104, 108 and the flip-flop 102. These are also reset (input "R") if the counts of counters 104 and 108 do not match ("N" output of comparator 110).

A similar procedure may be used to generate the table-switching signal based on monitoring the phase change of data signals or pilot tones as noted above. Further, although the operation of the event detector of figure 8 has been explained largely in terms of hardware, it will be understood that it may also readily be implemented in software, or in a combination of hardware and software, as is true of most of the elements described herein.

Still a further approach to detecting a disturbance event is to monitor the disturbance event directly. For example, in the case of off-hook or on-hook signals, a 48 volt dc step voltage is applied to the subscriber line. This signal is sufficiently distinct from other signals as to be readily detectable directly simply by monitoring the line for a step voltage of this size and thereafter generating a table-switching signal in response to its

detection. Another approach is to monitor the SNR on one or more subchannels by monitoring the "sync" frames. The presence of a disturbance from data sources on adjacent phone lines manifests itself as a change in the subchannel SNR. A direct method of monitoring disturbance events caused by activation or deactivation of communication-disturbing devices is to directly signal between the device and the local modem on occurrence of either of these events. As shown in Figure 3, for example, signaling lines 35, 37 may be extended directly between the local modem 34' and its associated devices 31, 32 to directly signal a change in these devices, such as their activation ("off hook") or deactivation ("on hook").

In addition to changing the control tables in response to a disturbance event, it is desirable to decrease the upstream transmit power level in order to minimize the interference with the voice communications caused by upstream transmissions, as well as to reduce the leakage of these transmissions into the downstream signal ("echo"). These interferences arise from nonlinearities caused by devices such as telephones that are coupled to the line, especially when the telephones are off-hook. The amount of power reduction required to render the interferences acceptable varies from one telephone to the next. In the preferred embodiment of the invention, a probing signal is used to determine the required decrease in upstream transmit power. In particular, after detecting a disturbance event such as activation or deactivation of a telephone or interference from other sources which can disrupt communications, the transmitter portion of the ATU-R (the "upstream transmitter") transmits a test signal over the subscriber line at varying power levels and measures the echo at the receiver portion of the ATU-R (the "downstream receiver"). The resultant measurement is used to determine an upstream transmission power level that minimizes echo at the downstream receiver or that at least renders it acceptable. The new power level, of course, is typically associated with a corresponding new parameter set in the channel control parameters.

In addition to changing the bit allocation and gain parameters in response to a disturbance event, it is generally necessary to change one or both of the subchannel equalizers, (i.e., the time-domain equalizers or the frequency-domain equalizers), as well as the echo canceller. Appropriate sets of these parameters may be formed in advance in the same manner as the bit allocations and channel gains (i.e., in a preliminary training

session, sending test communications over the subscriber line with various devices connected to the line activated, measuring the resultant communication conditions, and determining the various parameters based on the measurements), and stored in the secondary channel control table for recall and use as required. Alternatively, they may be redetermined quickly during a retraining operation following detection of a disturbance event and without excessivley disrupting communications, since these parameters are local to the receiver and thus need not be transmitted to the other modem in the communications pair.

In particular, in accordance with the preferred embodiment of the invention, on detecting a disturbance event, the transceivers enter a "fast retrain" phase, as shown in more detail in Figure 8. A common disturbance event is taking a telephone off hook or replacing it on hook, and this is commonly detected at the ATU-R. The fast retrain process will be illustrated for such an event, although it will be understood that it is not limited to this, and that the retrain may be initiated for any type of disturbance event, and at either end of the communication. Thus, on detecting such an event (Figure 8, event 200), the ATU-R notifies the ATU-C (step 202) to enter the fast retrain mode. The notification is preferably performed by transmitting a specific tone to the ATU-C, but may also comprise a message or other form of communication. On receiving this notification (step 204), the ATU-C awaits notification from the ATU-R of the power levels to be used for subsequent communications. This includes at least the upstream power level, and may include the downstream power level as well, since changing the upstream power level may impact downstream communications to some extent. For purposes of completeness, it will be assumed that both of these power levels are to be changed, although it will be understood that in many cases, only the upstream power level will be changed.

The new power levels to be used are determined by the ATU-R (step 208), which transmits a channel-probing test signal to the upstream transceiver and measures the resultant echo at the downstream receiver; it then sets the upstream power level to minimize the echo into the downstream signal, and may also set the downstream power level to minimize the effects of leakage of the upstream transmission into the downstream transmission at the upstream transmitter. The ATU-R then communicates (steps 210, 212) to the ATU-C the selected upstream and downstream transmission levels, e.g., by transmit-

ting to the upstream transceiver one or more tones modulated by binary PSK (phase shift keying) signals to ensure robust communication of the power levels. The power levels may be specified directly (e.g., as "-30dbm"), or indirectly (e.g., as "level 3" of a predefined group of levels), and the specification may identify the actual value of the power level, or simply the change in power level to be effectuated.

The ATU-R (step 214) and ATU-C (step 216) next commence transmission at the new power levels for purposes of retraining the equalizers and echo cancellers. Preferably, the change to the new power levels is synchronized through use of frame counters which are used in DSL systems to align transmitters and receivers, but the synchronization may be accomplished by other means (e.g., by transmitting a tone or message or by simply sending a flag) or may be left unsynchronized. Based on the training transmission, the ATU-R and ATU-C determine (steps 218, 220) the time and frequency domain equalizer parameters appropriate to the new power levels, as well as the appropriate echo canceller coefficients. The determination may include calculations based on these measurements in order to determine the coefficients, or the measurements may be used to select a particular set or sets of coefficients from one or more precalculated sets stored at the ATU-R and ATU-C, respectively.

For example, as was the case with determination of the power levels responsive to a disturbance event, the SNRs on various subchannels may be used to identify a particular device or devices associated with the event and thus to select an appropriate prestored parameter set stored at the ATU-R and ATU-C, respectively, simply by transmitting to the other modem in the communication pair a message or tone set that specifies the number of the parameter set to be used for subsequent communications. The SNR measurements thus serve as a "signature" of the device or devices associated with the disturbance event, and allow rapid identification of these devices. This approach can significantly reduce the time required to retrain the equalizers and echo cancellers. And even if training is required under particular circumstances, the training time can be meaningfully reduced by using prestored coefficients as the starting point.

To facilitate use of the SNR measurements in retrieving corresponding parameter sets, it is desirable that the various parameter sets as stored be indexed to sets of SNRs, so that one or more parameter sets associated with particular communication conditions

may quickly be identified and retrieved. One way in which this may be accomplished is shown in Fig. 9A in which the respective parameter sets such as a first set 250, a second set 252, etc. have, in addition to the subchannel (SC) number 254 and the corresponding bit allocation (BA) and gain (G) entries, a SNR entry 260 characteristic of the parameter set appropriate to a given communication condition, such as "on-hook" (table 250), "off-hook" (table 252), etc. Additional parameter sets such as frequency domain equalizer coefficients, time domain equalizer coefficients, and echo cancellation coefficients may also be stored in the tables, as would be appropriate for the receiver portion of the modem; for the transmitter portion, these coefficients are not applicable and thus are not stored.

An alternative means of linking the subchannel SNRs and the corresponding parameter sets is shown in Figure 9B. As there shown, a simple list structure 270 comprises a parameter set identifier 272, and a multiplicity of SNR measures 274, 276, etc. SNRs for some or all of the subchannels may be included. The list may be searched measure for measure to identify the nearest match to a stored parameter set, and that set then retrieved for subsequent use. In either Figure 9A or 9B the parameter set indexed to the SNRs may be a set of multiple parameters, such as bit allocations and gains, among others, of may comprise a single set such bit allocations only, or gains, only, etc.

The identification of the channel control parameter sets to be used for the subsequent communications is exchanged between the transceivers (steps 226-232) which then switch to these parameter sets (234, 236) and commence communications under the new conditions. The message containing the channel control parameters is preferably modulated in a similar manner as the "power level" message, i.e., using several modulating tones with BPSK signaling. The message is therefore short and very robust. It is important that it be short so that the fast retrain time is minimized, since the modem is not transmitting or receiving data during this time and its temporary unavailability may thus be very noticeable, as would be the case, for example, when the modem is being used for video transmission, or internet access, etc. Similarly, it is important that the message transmission be robust , since error-free communication during a disturbance event is very difficult, due to decreased SNR, impulse noise from ringing or dialing, or the like. Thus, the provision and utilization of pre-stored parameter sets significantly enhances the reli-

ability of communications despite the absence of a splitter at at least one of the modems and despite the presence of disturbance events concurrent with data communications.

It is expected that the modems described herein will most commonly be used in dedicated pairs, i.e., each subscriber (ATU-R) modem will communicate with a dedicated central office (ATU-C) modem. However, in certain cases it may suffice to provide a single master central office modem to service two or more subscriber modems. The present invention accommodates that eventuality as well. Thus, in Figure 10, a central office modem 280 communicates through a switch 282 with a plurality of subscriber modems 284, 286, 288 over subscriber lines 290, 292, 294. The modems may be located at differing distances from the central office and in different communication environments, and thus the channel control tables of each may be unique among themselves. Accordingly, the central office modem stores a master set 296 of individual channel control parameter sets 298, 300, 302, etc., one set (both transmit and receive) for each subscriber modem. On initiating communications to a particular subscriber, the central office modem retrieves the appropriate transmission parameter set for the subscriber and uses it in the subsequent communications. Similarly, on initiating communications to the central office, a given subscriber modem identifies itself to enable the central office modem to retrieve the appropriate reception parameter set for that subscriber.

CONCLUSION

From the foregoing it will be seen that we have provided an improved communications system for communication over subchannels of limited bandwidth such as ordinary residential telephone lines. The system accommodates both voice and data communications over the lines simultaneously, and eliminates the need for the installation and use of "splitters", an expense that might otherwise inhibit the adoption and use of the high communication capacity offered by DSL systems. Thus, it may be implemented and used as widely as conventional modems are today, but offers significantly greater bandwidth than is currently attainable with such modems.

CLAIMS

1. Apparatus for use in connection with a wireline data communication system carrying data in a multiplicity of different frequency bands which may be present concurrently on the line, comprising

A. means for detecting a signaling event associated with at least a first of said bands;

B. means responsive to said detecting means for modifying the processing of signals transmitted over at least a second of said bands.

2. Apparatus for use in connection with a wireline data communication system carrying data in a multiplicity of different frequency bands which may be present concurrently on the line and including means responsive to a signal resulting from a disturbance event to modify the transmission of data over said line.

3. Apparatus according to claim 2 in which said signal is a collection of PSK modulated tones.

4. Apparatus according to claim 2 in which said disturbance event is an on-hook to off-hook transition.

5. Apparatus according to claim 2 in which said disturbance event is off-hook to on-hook transition

6. Apparatus according to claim 2 in which said disturbance event is caused by a change in the crosstalk environment.

7. Apparatus according to claim 2 in which said modification of transmission includes sending a sequence of reference frames.

8. Apparatus according to claim 2 in which said modification of transmissionincludes entering a fast retrain mode.

9. Apparatus according to claim 1 in which said detecting means comprises

(1) means for measuring, at a multiplicity of different times, a characteristic of a signal transmitted over said wireline

(2) means for activating said modifying means when samples of the measured characteristics differ in a defined manner at selected different times.

10. Apparatus according to claim 9 in which said measuring means measures the extent of errors in error-correcting code associated with the signals whose processing is to be modified and activates said modifying means only when the extent of said errors exceeds a defined threshold for at least a defined number of times.

11. Apparatus according to claim 10 in which said measuring means activates said modifying means only when the number of errors in each said sample exceeds a defined number in each of two or more samples.

12. Apparatus according to claim 9 in which said measuring means measures a characteristic of signals transmitted over a plurality of different frequency bands and activates said modifying means only when the measured characteristic exceeds defined thresholds associated with each of said plurality of frequency bands.

13. Apparatus according to claim 1 in which said wireline data communication system comprises a telephone subscriber loop carrying both voice and data signals, and in which said signaling event comprises an off-hook event.

14. Apparatus according to claim 1 in which said wireline data communication system comprises a telephone subscriber loop carrying both voice and data signals, and in which said signaling event comprises an on-hook event.

15. Apparatus according to claim 14 which includes a frequency domain equalizer for equalizing the frequency characteristics of each of said frequency bands in accordance with reference signals transmitted over said bands and in which said modifying means comprises means for changing the characteristics of said equalizers in accordance with

measurements on said reference signals.

16. Apparatus according to claim 9 in which said measuring means measures the signal-to-noise ratio of said reference signals and activates said modifying means only when said ratio is less than a defined threshold for at least a defined number of times

17. Apparatus according to claim 9 in which said data communication system includes means for transmitting a pilot tone and in which said apparatus includes means for measuring at least one characteristic of said tone at different times and means for activating said modifying means only when said characteristics manifest changes exceeding a defined threshold for at least a defined number of times.

18. Apparatus according to claim 9 which includes means for transmitting over said wireline information back to a source of said information signals, said means transmitting at a first power level in the absence of detection of a signaling event, and transmitting at a different power level responsive to detection of a signaling event.

19. Apparatus according to claim 9 which includes a first set of stored parameters for use in processing said information when said system is in a first state.

20. Apparatus according to claim 19 which further includes a second set of stored parameters for processing said information when said system switches to a second state responsive to detecting a signaling event.

21. Apparatus according to claim 20 in which said second set is precomputed.

22. Apparatus according to claim 21 in which said second set is computed responsive to reference signals received on said subchannel subsequent to detection of a signaling event.

23. Apparatus according to claim 21 in which said first and second sets are computed on initiating a communications session.

24. Apparatus according to claim 1 including means for varying the data rate at which said modifying meansprocesses said signals.

25. In a modem communicating data over a multiplicity of discrete sub-subchannels, each

characterized by a bit allocation parameter defining the allocation of bits to the corresponding subchannel for communication over said subchannel, the improvement comprising:

A. means for storing a first channel control table for allocating bits to said subchannel during a first communication condition;

B. means defining a second channel control table for allocating bits to said table during a second communication condition;

26. A modem according to claim 25 which includes a

means for switching between said tables on the detection of a defined event.

27. A modem according to claim 25 in which said first table establishes the communications capabilities of said modem during normal operation.

28. A modem according to claim 27 in which said second table establishes the communications capabilities of said modem during diminished operation.

29. A modem according to claim 25 in which said defined event includes signaling events comprising transitions between on-hook and off-hook conditions.

30. A modem according to claim 29 in which said first table defines communications in the absence of a signaling event.

31. A modem according to claim 30 in which said second table defines communications responsive to detection of a signaling event.

32. A modem according to claim 31 in which said switching means switches from said second table to said first table on detection of a signaling event indicative of cessation of a previously-detected signaling event.

33. A modem according to claim 25 in which said first and second tables are determined during an initialization session in which the communication capabilities of said sub-subchannels are determined.

34. A modem according to claim 33 in which said first table is determined in the absence of interfering signaling conditions.

35. A modem according to claim 34 in which said second table is determined as a function of said first table.

36. A modem according to claim 35 in which the bit allocations of said second table are determined as a percentage of the bit allocations of said first table.

37. A modem according to claim 27 in which the bit allocations of second table are determined by adding noise margins to the determination of the bit allocations of the corresponding sub-subchannels of said first table.

38. A modem according to claim 25 in which said second channel control table is determined responsive to a plurality of signaling events created by a corresponding plurality of event-generating sources, each defining a channel control table specific to the given source, and comprises a composite table formed by selecting, for each sub-subchannel, the minimum bit allocation for the corresponding sub-subchannel of the table associated with each of the plurality of sources.

39. A modem according to claim 25 in which said second channel control table is selected from a plurality of tables determined responsive to a plurality of signaling events created by a corresponding plurality of event-generating sources, each defining a channel control table specific to the given source.

40. A modem according to claim 39 which includes means for selecting one of said plurality of tables for use as said second table in accordance with the source generating an event.

41. A modem according to claim 25 which further includes:

C. means for redetermining said channel control tables while said modem is in either of said communication conditions; and

D. means for communicating a redetermined table to a second modem en-

gaged in communication with said modem.

42. A modem according to claim 41 in which said communicating means communicates said redetermined table over a dedicated sub-subchannel selected from among said discrete sub-subchannels.

43. A modem according to claim 41 in which said communicating means further communicates to said second modem information identifying the type of said redetermined table.

44. A modem for use in asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of sub-subchannels, said loop adapted to carry both voice and data communications thereon, comprising:

A. means for storing a first table defining data communications between said modem and a second modem connected to said loop during a first communication state;

B. means for storing a second table defining data communications between said modem and said second modem during a second communication state.

45. A modem according to claim 44 that includesmeans for switching between said tables responsive to the occurrence of selected events.

46. A modem for use in asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of sub-subchannels, said loop adapted to carry both voice and data communications thereon, comprising:

A. means for storing a first table defining data communications between said modem and a second modem connected to said loop during a first communication state;

B. means for storing a second table defining data communications between said modem and said second modem during a second communication state; and

C. means for selecting between said tables based on signals received from

said second modem.

47. A modem according to claim 44 which includes:

D. means for detecting said selected events, said means including

(1) means for monitoring a selected characteristic of at least one of said communication subchannels during a plurality of communication intervals;

(2) means for determining differences in the selected characteristic over said plurality of intervals;

(3) means for generating a signal initiating switching of said tables when said differences exhibit a defined pattern.

48. A modem according to claim 47 in which said pattern comprises an initial difference above a first threshold amount followed by at least a subsequent differences less than a second threshold amount.

49. A modem according to claim 48 in which said first threshold is greater than said second threshold.

50. A modem according to claim 49 in which said pattern comprises an initial difference above a first threshold amount followed by a plurality of subsequent differences less than a second threshold amount.

51. A modem according to claim 48 in which said selected characteristic is monitored over at least one sub-subchannel.

52. A modem according to claim 48 in which said selected characteristic is monitored over a plurality of sub-subchannels.

53. A modem according to claim 52 which includes means for averaging the monitored values of said selected characteristic over said sub-subchannels for use in comparing said initial difference to said first threshold.

54. A modem according to claim 52 which includes means for averaging the monitored

values of said selected characteristic over said sub-subchannels for use in comparing said subsequent difference to said second threshold.

55. A modem according to claim 49 in which said characteristic comprises an error code error.

56. A modem according to claim 49 in which said characteristic comprises a signal-to-noise ratio.

57. A modem according to claim in which said characteristic comprises a parameter of a pilot tone.

58. A modem according to claim 44 in which said first table establishes a data rate greater than that of said second table.

59. A modem according to claim 58 in which said tables define the number of bits transmitted over the respective sub-subchannels.

60. A modem according to claim 59 in which said events comprise signaling events selected from the group comprising off-hook, on-hook, ringing, and busy.

61. A modem according to claim 47 in which said switching means returns said modem to said first communication state on termination of the event causing the switching.

62. A modem according to claim 44 which includes:

D. means for emitting into said loop a test signal for probing the return characteristics of transmissions into the loop by said modem; and

E. means for limiting the power level of said transmissions in accordance with the measured return characteristics.

63. A modem according to claim 62 in which said probe comprises a tone at a defined amplitude and frequency and in which the measured return characteristics comprise at least one characteristic selected from the group comprising the amplitude and frequency of the signal returned to said modem in response to emission of said tone.

64. A modem according to claim 62 in which said probe comprises a plurality of tones at defined amplitudes and frequencies and in which the measured return characteristics comprise at least one characteristic selected from the group comprising the amplitudes and frequencies of the signal returned to said modem in response to emission of said tone.

65. A modem according to claim 44 which includes equalizers for equalizing the transmission characteristics of said subchannels and in which said tables define:;

(1) coefficients of time domain equalizers or

(2) coefficients of frequency domain equalizers or

(3) coefficients of digital echo cancellers

66. A modem according to claim 44 in which said first table is determined during an initialization process in the absence of a selected event.

67. A modem according to claim 66 in which said second table is determined during an initialization process in the presence of a selected event.

68. A modem according to claim 67 in which said second table is redetermined responsive to occurrence of a selected event.

69. A modem according to claim 68 in which redetermined tables are communicated from a given modem to other modems with which it is in communication during a quiescent state.

70. A modem according to claim 47 in which said generating means causes transmission of a switch-control signal over one of said sub-subchannels in response to detection of a selected event.

71. A modem according to claim 47 in which said generating means causes transmission of a tone in response to detection of a selected event.

72. Apparatus for use in communicating digital data over a digital subscriber line concurrent with voice communications over said line, comprising:

A. a transceiver for communicating digital data to and from said line;

B. a first storage element for storing a first set of communication parameters for use in communicating data under a first communication condition; and

C. a second storage element for storing a second set of communication parameters for use in communicating data under a second communication condition.

73. Apparatus according to claim 72 including a means for monitoring communication conditions on said line and for switching between said first and second sets of communication parameters responsive to changes between said communication conditions.

74. Apparatus according to claim 72 including means responsive to signals communicated to it to switch between said sets of communicaton parameters.

75. Apparatus according to claim 72 which communicates said data over a plurality of subchannels of different frequency and at least potentially different information-carrying capacity and in which said communication parameters comprise at least a channel control table defining the number of bits to be allocated to the subchannels for communications under the respective conditions.

76. Apparatus according to claim 72 which communicates said data over a plurality of subchannels of different frequency and at least potentially different information-carrying capacity and in which said communication parameters comprise subchannel gain tables defining the gain characteristics of the subchannels for communications under the respective conditions.

77. Apparatus according to claim 72 which communicates said data over a plurality of subchannels of different frequency and at least potentially different information-carrying capacity and in which said communication parameters comprise frequency domain equalizers defining the frequency characteristics of the subchannels for communications under the respective conditions.

78. Apparatus according to claim 72 in which both sets of communication parameters are determined during an initialization interval preceding communication of working data.

79. Apparatus according to claim 72 in which said first set of communication parameters is determined during an initialization interval preceding communication of working data and said second set of parameters is determined during a subsequent interval following communication of working data and characterized by said second communications conditions.

80. Apparatus according to claim 79 in which said second set of communication parameters is determined at a first transceiver of a transceiver pair in communication with each other and is communicated to a second transceiver in said pair during a time when said transceivers are operating with an earlier set of set of secondary parameters.

81. Apparatus according to claim 80 in which said transceivers revert to said first set of communications parameters responsive to return of communications to a first communications condition.

82. Apparatus according to claim 72 which includes means for signaling between said transceivers a desired change in communications parameters.

83. Apparatus according to claim 82 in which said signaling means comprises means for transmitting messages over one or more subchannels.

84. Apparatus according to claim 82 in which said signaling means comprises means for transmitting messages over one or more subchannels intermediate subchannels used for upstream and downstream communications.

85. Apparatus according to claim 83 in which said messages comprise tones.

86. Apparatus according to claim 72 in which said transceiver transmits and receives data over a defined number of subchannels and which includes means for identifying the subchannels over which said transceivers will communicate with each other.

87. Apparatus according to claim 86 in which said identifying means includes means for nulling at least those portions of the stored sets of communications parameters that define the bit capacity of the subchanels that are being excluded from communications.

88. Apparatus according to claim 72 in which said second set of parameters includes communication parameters corresponding to a plurality of devices connected for voice communications over said line.

89. Apparatus according to claim 80 in which said second set of parameters includes a plurality of subsets of communications parameters characteristic of a corresponding plurality of voice communication devices for defining communications when a selected device is active.

90. Apparatus according to claim 89 including means for identifying which of said plurality of devices is active and for selecting the corresponding communications parameter set for such device.

91. Apparatus according to claim 90 in which said identifying means includes signaling means interconnecting said voice communication devices to said transceiver.

92. In a communication system using discrete multitone modulation, the improvement comprising storing a first channel control table for use in defining communications under a first communication state and storing at least a second channel control table for communication under a second communication state.

93. A modem for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of sub-subchannels, comprising:

A. means for storing a first table defining data communications between said modem and a second modem connected to said loop during a first communication state;

B. means for storing a second table defining data communications between said modem and said second modem during a second communication state:

94. A modem according to claim 93 that includes means for switching between said tables responsive to the occurrence of selected events.

95. A modem according to claim 94 in which said selected event includes a transition

from on-hook to off-hook.

96. A modem according to claim 94 in which said selected event includes a transition from off-hook to on-hook.

97. A modem according to claim 94 in which said selected event includes a change in the crosstalk environment.

98. A modem according to claim 93 that includes means for switching between said tables based upon reception of a signal from a remote modem.

99. A modem according to claim 98 in which said signal includes a message.

100. A modem according to claim 98 in which said signal includes a tone or set of tones.

101. A modem according to claim 98 in which said signal includes a flag.

102. A modem according to claim 93 that includes means for switching between said tables at a time that depends upon a frame counter.

103. A modem according to claim 93 that includes means for switching between said tables at a time that depends upon a flag.

104. A multicarrier modem for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of subchannels that includes a means to select the number of said subchannels that are to be used for communications based upon a signal from a remote modem.

105. A modem according to claim 104 in which said signal is received prior to initialization of modem.

106. A modem according to claim 104 in which said signal is a message dictating how many subchannels are to be used.

107. A modem according to claim 104 in which said signal is a message selecting one of a collection of candidate subchannel selections.

108. A modem according to claim 104 in which said signal is a tone or collection of tones selecting one of a collection of candidate subchannel selections.

109. A multicarrier modem for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of subchannels that includes a means to signal to a remote modem the number of said subchannels that are to be used for communications.

110. A modem according to claim 109 in which said signal is transmitted prior to initialization of modem.

111. A modem according to claim 109 in which said signal is a message dictating how many subchannels are to be used.

112. A modem according to claim 109 in which said signal is a message selecting one of a collection of candidate subchannel selections.

113. A modem according to claim 109 in which said signal is a tone or collection of tones selecting one of a collection of candidate subchannel selections.

114. A multicarrier modem for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of subchannels, comprising of a means to limit the number of transmission subchannels in order to communicate with a remote modem that is only capable of receiving the limited frequency band.

115. A multicarrier modem for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels formed from a plurality of subchannels, comprising of a means to limit the number of receiver subchannels in order to communicate with a remote modem that is only capable of transmitting the limited frequency band.

116. A multicarrier modem that for use in symmetric or asymmetric digital subscriber loop communications having both upstream and downstream communication subchannels

formed from a plurality of subchannels, comprising of a means to determine the location of a telephone that would benefit from the use of a low pass filter.

117. A multicarrier modem according to claim 116 in which said determination means includes monitoring the signal to noise ratio when said telephone goes off-hook.

118. A multicarrier modem according to claim 116 in which said determination means includes monitoring the echo response of the transmitted signal when said telephone goes off-hook.

119. In a modem communicating data over a wireline via a multiplicity of discrete sub-channels in accordance with a bit-loading specification defining the allocation of bits to the corresponding subchannel for communication thereon, the improvement comprising:

A irst means for storing a primary bit allocation table for allocating said bits during a first communication condition; and

B. second means for storing a secondary bit allocation table for allocating said bits during a second communication condition.

120. A modem according to claim 119 which includes means for switching between bit allocation sets defined by said tables.

121. A modem according to claim 120 in which said switching means is actuated respon-sive to at least one of the events comprising receipt of a message, a tone, or a flag from a remote modem.

122. A modem according to claim 121 in which switching means includes the use of a frame counter to designate when said switch is to occur.

123. A modem according to claim 119 in which said primary bit allocation table defines communications in the absence of a disturbance event, and in which said secondary bit allocation table defines communications in response to said disturbance event.

124. A modem according to claim 123 in which said secondary bit allocation table defines communications over said subchannels for times when said subchannels are affected by

voice communication activities.

125. A modem according to claim 124 in which said secondary bit allocation table defines communications over said subchannels for times when said subchannels are affected by voice communication devices that have entered the off-hook state.

126. A modem according to claim 124 in which said primary bit allocation table defines communications over said subchannels for times when said subchannels are affected by voice communication devices that have returned from an off-hook state.

127. A modem according to claim 119 in which said primary table is determined in a preliminary training session in which potentially interfering voice communication devices connected to the line are inactive.

128. A modem according to claim 119 in which said primary table is determined in the absence of disturbance events.

129. A modem according to claim 119 in which said primary bit allocation table is determined in advance of installation of said modem.

130. A modem according to claim 119 in which said secondary table is determined in an initial training session based on measurements of communications over said wireline.

131. A modem according to claim 119 in which said secondary table is determined in initial training sessions based on measurements of communications over said wireline with potentially interfering voice communication devices connected to the line selectively activated to thereby form a secondary table comprising a plurality of bit allocation sets corresponding to the plurality of activated devices.

132. A modem according to claim 131 in which said devices are activated one by one so that each bit allocation set corresponds to a single device.

133. A modem according to claim 131 in which said devices are activated in groups of two or more so that each bit allocation set corresponds to one of said groups.

134. A modem according to claim 119 in which said secondary bit allocation table is de-

termined from said primary bit allocation table.

135. A modem according to claim 119 in which the bit allocations of said secondary table are determined as a percentage of the bit allocations of said primary table.

136. A modem according to claim 119 in which the bit allocations of said secondary table are determined based on a percentage of the signal to noise ratios on which the bit allocations of said primary table are determined.

137. A modem according to claim 119 in which the bit allocations of said secondary table are determined based on information defining said primary table but using a different bit error rate

138. A modem according to claim 119 in which said secondary bit allocation table is formed as a composite of the bit loading sets of a multiplicity of voice communication devices and/or disturbances.

139 A modem according to claim 119 in which the bit allocation value for each subchannel in said composite is the worst-case value for the corresponding subchannel in the bit allocation sets defining said devices and/or disturbances.

140. A modem according to claim 119 in which said secondary bit allocation table is determined by adding a power margin to the calculations for the respective entries of the primary table.

141. A modem according to claim 119 in which said secondary table comprises a set of bit allocation tables defining the bit allocations for a corresponding set of devices that may be connected to said wireline.

142. A modem according to claim 119 in which said secondary table comprises a set of bit allocation tables defining the bit allocations for a corresponding set of disturbances on said wireline.

143. A modem according to claim 119 in which said secondary table comprises a set of bit allocation tables defining the bit allocations for a corresponding set of devices and

disturbances on said wireline.

144. A modem according to claim 119 in which a plurality of secondary bit allocation tables are determined by adding a corresponding plurality of power margins to the calculations for the respective entries of the primary table, each secondary table so determined corresponding to a different communications state.

145. A modem according to claim 119 in which said power margin is substantially uniform across the entries of a table.

146. A modem according to claim 119 in which said power margin varies across the entries of a table.

147. A modem according to claim 119 configured to switch to a secondary state corresponding to use of said secondary bit allocation table for communications responsive to occurrence of a disturbance event.

148. A modem according to claim 147 configured to switch to a primary state corresponding to use of said primary bit allocation table for communications responsive to cessation of a disturbance event.

149. A modem according to claim 147 configured to switch to a different secondary state corresponding to use of a different set of bit allocations in said secondary bit allocation table for communications responsive to occurrence of a further disturbance event, different from a disturbance event preceding it, while said modem is in said secondary state.

150. A modem according to claim 119 in which said switching means includes means responsive to a disturbance event to thereby initiate a switch between said tables.

151. A modem according to claim 150 which includes a signaling line connecting a device to said modem for signaling to said modem the occurrence of a disturbance event.

152. A modem according to claim 150 which includes means for detecting a disturbance event on said line.

153. A modem according to claim 152 in which said detecting means includes means for

monitoring the signal to noise ratios on one or more subchannels of said line and means responsive to said ratios for selecting a bit allocation set for use in communications.

154. A modem according to claim 152 in which said detecting means includes means for monitoring a parameter of a tone or collection of tones and means responsive to said parameter for selecting a bit allocation set for use in communications.

155. A modem according to claim 152 in which said parameter includes the amplitude and/or phase of said tone or tones.

156. In a modem communicating data over a wireline via a multiplicity of discrete subchannels in accordance with a gain specification defining the allocation of gains to the corresponding subchannel for communication thereon, the improvement comprising:

A. first means for storing a primary gain set for allocating said gains during a first communication condition; and

B. second means for storing a secondary gain set for allocating said gains during a second communication condition.

157. A modem according to claim 156 which includes means for switching between said gain sets.

158. A modem according to claim 157 in which said switching means is actuated responsive to at least one of the events comprising receipt of a message, a tone, or a flag from a remote modem.

159. A modem according to claim 157 in which said switching means is actuated responsive to its detection of a disturbance event.

160. A discrete multitone modem including a transmitter for communicating to a remote receiver at one of a plurality of power levels associated with particular communication conditions on a digital subscriber line, comprising

A. means for monitoring at least one parameter indicative of communication conditions on said line;

B. means dependent on said parameter for selecting the power level at which said modem either transmits, or receives, data or both.

161. A discrete multitone modem including a transmitter for communicating to a remote receiver at one of a plurality of power levels associated with particular communication conditions on a digital subscriber line and adapted to receive a power select signal indicating a power level to be used for subsequent transmissions.

162. A discrete multitone modem according to claim 160 which includes means for communicating to another modem with which it communicates a power select signal indicating a power level to be used for subsequent transmissions.

163 A discrete multitone modem according to claim 160 which includes means for receiving from another modem with which it communicates a power select signal indicating a power level to be used for subsequent transmissions.

164 A discrete multitone modem according to claim 160 in which said power select signal identifies a specific power level at which said other modem is to receive data from it.

165. A discrete multitone modem according to claim 162 in which said power select signal identifies a specific power level at which said other modem is to transmit data to it.

166. A discrete multitone modem according to either of claims 164 or 165in which said discrete power level comprises one of several predefined power levels for communication between said modems.

167. A discrete multitone modem according to claim 162 in which the means for communicating said power select signal includes means for transmitting said signal over at least one subchannel intermediate an upstream and a downstream set of data subchannels over which said modem communicates.

168. A discrete multitone modem according to claim 167 which the means for communicating said power select signal includes means for transmitting said signal over one or more data subchannels over which said modem communicates.

169. A discrete multitone modem according to claim 160 which includes a plurality of parameter sets stored in said modem and defining communications under a plurality of different communication conditions on said line.

170. A discrete multitone modem according to claim 169 in which said parameter sets include at least a primary set of parameters for controlling communications in the absence of a disturbance event, and a secondary set for controlling communications responsive to a disturbance event.

171. A discrete multitone modem according to claim 169 in which said monitoring means monitors the signal to noise ratio on one or more subchannels over which said modem communicates and selects a parameter set based on said ratio for controlling subsequent communications.

172. A discrete multitone modem according to claim 169 in which said parameter sets include a set of parameters defining the power level at which said modem transmits to other modems.

173. A discrete multitone modem according to 169 in which said parameter sets include a set of parameters defining the power level at which said modem receives communications from other modems.

174. A discrete multitone modem according to claim 173 in which said modem includes means for transmitting to another modem with which it is in communication a signal indicating a parameter set to be used in subsequent communications between said modems.

175. A discrete multitone modem according to claim 172 in which said modem includes means for receiving from another modem with which it is in communication a signal indicating a parameter set to be used in subsequent communications between said modems.

176. A discrete multitone modem according to claim 160 in which said modem communicates to another modem a desired power level by itself changing the power level at which it communicates with said other modem.

177. A discrete multitone modem including a transmitter for communicating to a remote receiver at one of a plurality of power levels associated with particular communication conditions on a digital subscriber line and storing a plurality of sets of channel control parameters corresponding to said power levels, comprising

A. means responsive to a disturbance event to select a power level at which said transmitter transmits to said receiver; and

B. means for communicating the selected power level to said receiver.

178. A discrete multitone modem including a transmitter for communicating to a remote receiver at one of a plurality of power levels associated with particular communication conditions on a digital subscriber line and storing a plurality of sets of channel control parameters corresponding to said power levels and adapted to receive a power select signal indicating a power level to be used for subsequent transmissions.

179. A discrete multitone modem according to claim 177 in which the means for communicating the change in power level transmits a power power select signal to the remote receiver indicative of the change in power level.

180. A discrete multitone modem according to claim 179 in which the transmitting means transmits a tone indicating the desired change in power level to the remote receiver.

181. A discrete multitone modem according to claim 179 in which the transmitting means transmits a plurality of tones indicating the desired change in power level to the remote receiver.

182. A discrete multitone modem according to claim 181 in which the plurality of tones designates a particular one of several power levels to which the remote receiver is to switch.

183. A discrete multitone modem according to claim 179 in which the means for communicating the change in power level designates a particular one of several power levels to which the remote receiver is to switch.

184. A discrete multitone modem according to claim 179 in which the means for communicating the change in power level to the remote receiver includes means for transmitting a power power select signal over at least one subchannel intermediate an upstream and a downstream set of data subchannels over which said modem communicates.

185. A discrete multitone modem according to claim 177 in which the means for communicating the change in power level to the remote receiver comprises

(1) means associated with the transmitter for effectuating the change in power level at said transmitter;

(2) means in the remote receiver responsive to the change in power level at the transmitter for changing the power level of its reception in accordance therewith.

186. A discrete multitone modem according to claim 177 in which the means for communicating the change in power level to the remote receiver transmits to the remote receiver a frame count at which the remote receiver is to effectuate the change in power level.

187. A discrete multitone modem according to claim 178 in which the means for receiving the power select signal inlcudes a frame count at which said modem is to effectuate the change in power level.

188. A discrete multitone modem according to claim 177 including a receiver responsive to communication of a power level change from a remote transmitter to thereby:

(1) measure at least one parameter indicative of communication conditions on said line responsive to said power level change, and

(2) select new channel control parameters from a plurality of sets of prestored channel control parameters based on said measurement.

189. A discrete multitone modem according to claim 188 which said at least one parameter comprises a signal to noise ratio of communications over said line.

190. A discrete multitone modem according to claim 188 which said at least one parameter comprises a characteristic of a monitor tone transmited over said line.

191. A discrete multitone modem according to claim 188 which said characteristic comprises at least the amplitude of said tone.

192. A discrete multitone modem according to claim 188 which said characteristic comprises at least the phase of said tone.

193. A discrete multitone modem according to claim 188 which said characteristic comprises at least the frequency of said tone.

194. A discrete multitone modem according to claim 189 in which said tone is transmitted over over at least one subchannel intermediate an upstream and a downstream set of data subchannels over which said modem communicates.

195. A discrete multitone modem according to claim 189 in which said signal to noise ratio is based on measurements of reference frames transmitted over said line.

196. A discrete multitone modem according to claim 26 in which said signal to noise ratio is based on measurements of data transmitted over said line.

197. A discrete multitone modem according to claim 177 in which the means responsive to a disturbance event comprises means for measuring at least one characteristic of said line indicative of communications on said line and for selecting a power level responsive to said measurement.

198. A discrete multitone modem according to claim 197 in which said characteristic comprises CRC errors and in which said measuring means signals a change in power level when said CRC errors exceed a defined threshold on a selected plurality of successive measurements thereof.

199. A discrete multitone modem according to claim 197 in which said characteristic comprises forward error correction coefficients and in which said measuring means signals a change in power level when the number of errors exceeds a defined threshold.

200. A discrete multitone modem according to claim 199 in which said measuring means signals a change in power level when the number of uncorrected errors exceeds a defined threshold.

201. A discrete multitone modem according to claim 199 in which the means for communicating the change in power level designates a single alternative power level to which the remote receiver is to switch.

202. A discrete multitone modem according to claim 177 which includes means in said modem for at least one parameter indicative of communication

203. A method of transmitting data over a wire line through upstream and downstream channels, respectively, from first and second pluralities of discrete-frequency subchannels, comprising the steps of:

A. storing at least first and second parameter sets defining data communications over said channels under at least two different communication conditions;

B. selecting a parameter set for use in communications in accordance with the prevailing communication condition.

204. The method of claim 203 in which said selecting step includes the step of monitoring communications on said line and transmitting and selecting said parameter set in accordance with said monitoring.

205. The method of claim 204 in which said monitoring step includes the step of measuring at least one communication indicium on said at least one subchannel.

206. The method of claim 205 in which said at least one indicium is selected from the group comprising signal to noise ratios, error rates, and the amplitude and frequency of tones.

207. The method of claims 203 or 206 which includes the step of transmitting over said line a signal that identifies the parameter set to be selected.

208. The method of claims 203 or 206 which includes the step of receiving over said line a signal that identifies the parameter set to be selected.

209. The method of claim 207 in which said signal is transmitted on a subchannel intermediate said upstream and downstream channels.

210. The method of claim 208 in which said signal is received on a subchannel intermediate said upstream and downstream channels.

211. The method of claims 203, 206 or 207 in which said first parameter set defines communications over said line in the absence of a disturbance event and said second parameter set defines communications over said line in the presence of a disturbance event.

212. The method of claims 203 or 211 in which said parameter sets include at least one parameter set from the group comprising subchannel bit allocations subcahnel gains.

213. The method of claims 203 or 211 in which said parameter sets include at least one parameter set from the group comprising subchannel frequency domain coefficients, time domain coefficients, and echo cancellation coefficients.

214. The method of claims 212 or 213 in which said parameter sets include a first section for use in transmitting data over said line and a second portion for receiving data over said line.

215. A method of transmitting data over a wire line through upstream and downstream channels, respectively, from first and second pluralities of discrete-frequency subchannels, comprising the steps of:

A. signaling over said line to a remote receiver the intention to transmit data over said line at a selected one of a plurality of predefined power levels;

B. transmitting data over said line at said selected power level

216. The method of claims 214 or 219 which includes the step of monitoring communications conditions on said line and selecting said power level in accordance therewith.

217. The method of claims 215 or 219 in which the step of selecting said power level includes the step of selecting a first power level in response to detecting the absence of a disturbance event and selecting a second power level in response to detecting the presence of a disturbance event.

218. The method f claim 217 in which said second power level is selected from a group of at least two power levels.

219. A method of transmitting data over a wire line through upstream and downstream channels, respectively, from first and second pluralities of discrete-frequency subchannels, comprising the steps of:

A. signaling to a remote receiver at one of a plurality of power levels;

B. receiving a signal from a receiver that determines said power levels.

220. The method of claim 219 in which said power levels are selected from a plurality of predetermined power levels having corresponding pre-stored parameter sets.

221. The method of claim 219 in which said power levels are received via said signal from said remote receiver.

222. The method of claim 219 in which said signal includes at least one signal selected from the group comprising a message, a tone, a collection of tones, or a flag.

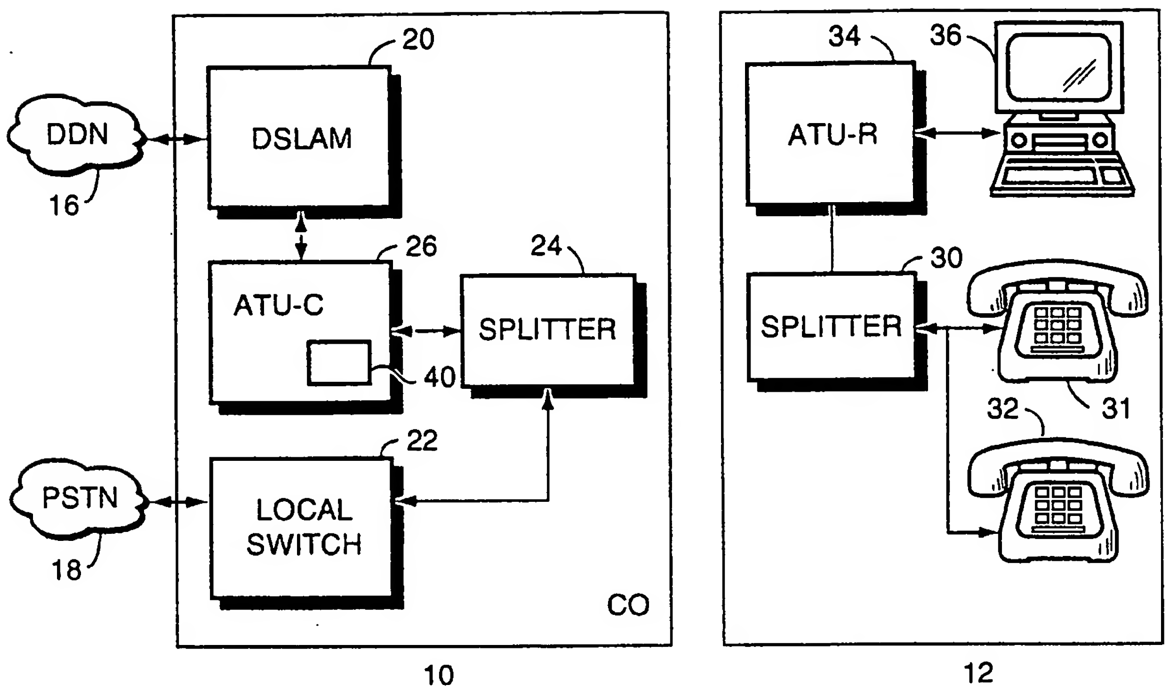

FIG. 1 (PRIOR ART)

	50	52	54
	SC	B	G
		⋮	⋮
42a	9	6	8
	10	6	8
	11	5	9
	12	6	8
		⋮	⋮
42b	40	6	25
	41	6	26
	42	5	27
	43	4	28

42

FIG. 2 (PRIOR ART)

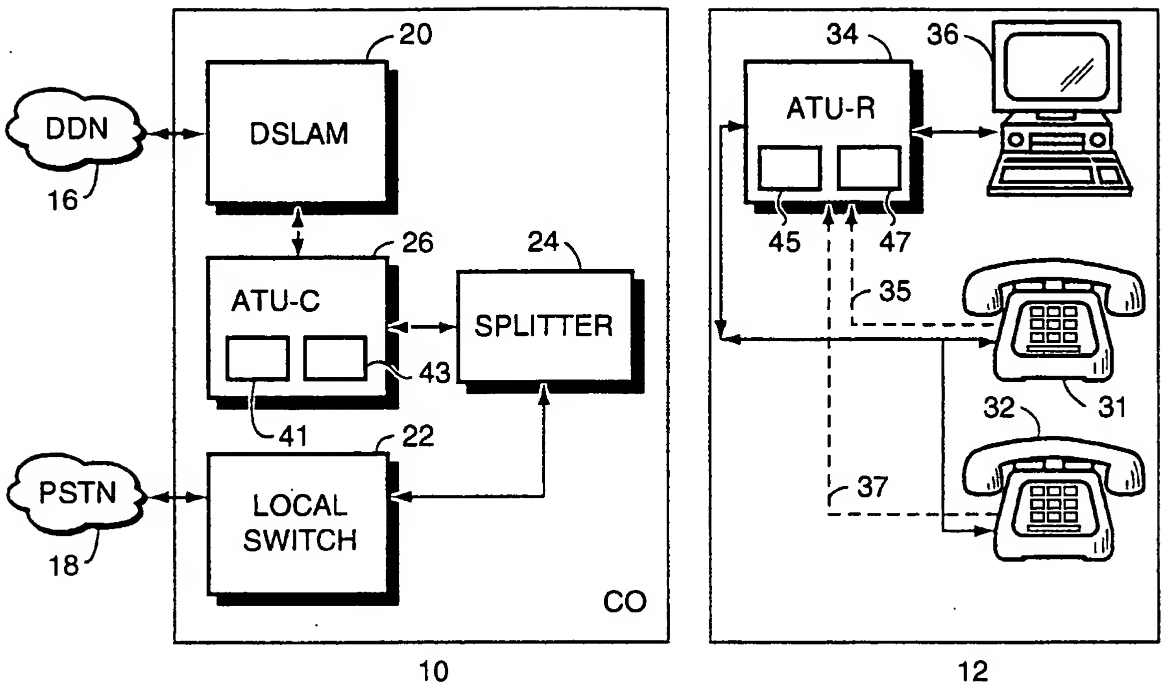
DDN
16
DSLAM
20
ATU-C
26
43
41
SPLITTER
24
PSTN
18
LOCAL SWITCH
22
CO
10
ATU-R
34
36
45
47
35
31
32
37
12

FIG. 3

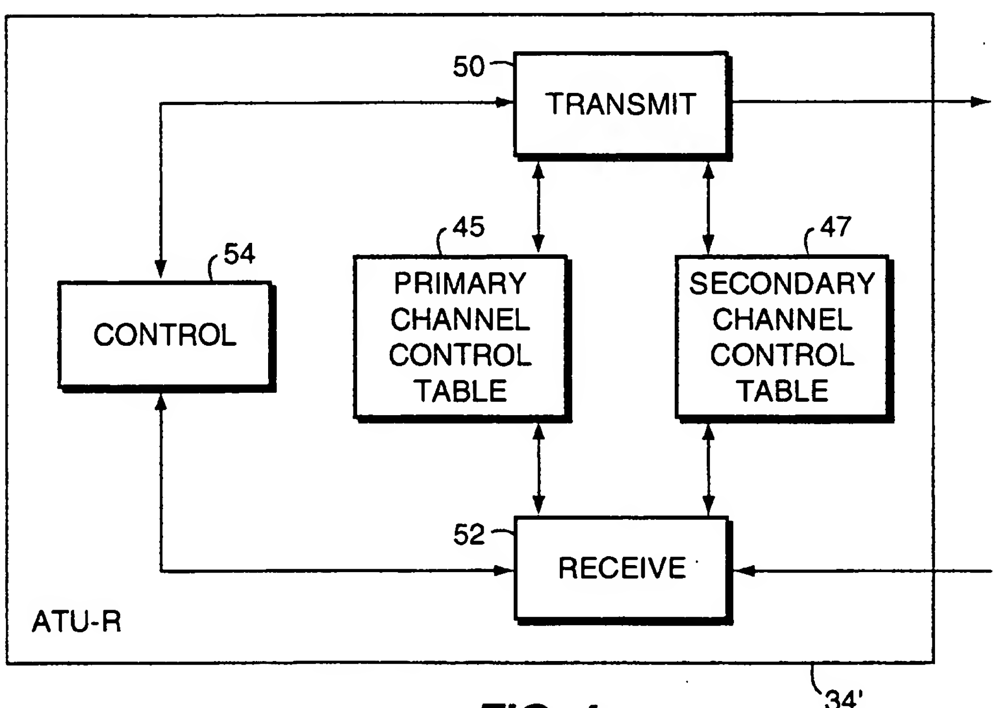
50
TRANSMIT
54
CONTROL
45
PRIMARY CHANNEL CONTROL TABLE
47
SECONDARY CHANNEL CONTROL TABLE
52
RECEIVE
ATU-R
34'

FIG. 4

45c 45d 45e 45f 45g 45h

	SC	B	G	FDQ	TDQ	EC
45a	9	8	0			
	10	8	0			
	11	7	1			
	12	8	0			
45b	40	7	1	a	c	e
	41	7	1	a	c	e
	42	7	1	a	c	e
	43	6	1.3	b	d	f
	:	:	:	:	:	:

FIG. 5A

47a

47f 47g 47h 47i 47j 47b 47c 47c

	SC	B	G	FDQ	TDQ	EC	B	G	FDQ	TDQ	EC	B	G	FDQ	TDQ	EC
47d	9	7	1				8	-8				8	-8			
	10	6	1.3				8	-8				8	-8			
	11	7	1				7	-8				7	-8			
	12	7	1				8	-8				8	-8			
47e	40	7	1	g	i	k	7	1	m	p	s	6	1.3	u	x	t
	41	7	1	g	j	k	6	1.3	n	q	t	4	1.6	v	y	1
	42	7	1	h	i	k	5	1.5	o	r	u	5	1.5	w	z	r
	43	6	1.3	g	i	l	6	1	n	q	t	6	1.3	v	x	t
	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:

47

FIG. 5B

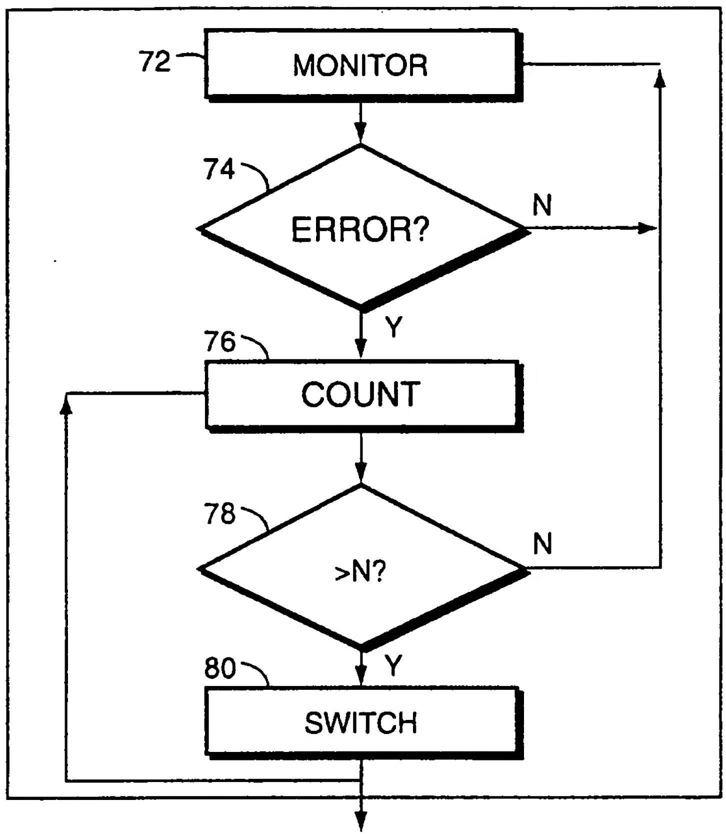
72
MONITOR
74
ERROR?
N
Y
76
COUNT
78
>N?
N
Y
80
SWITCH

FIG. 6

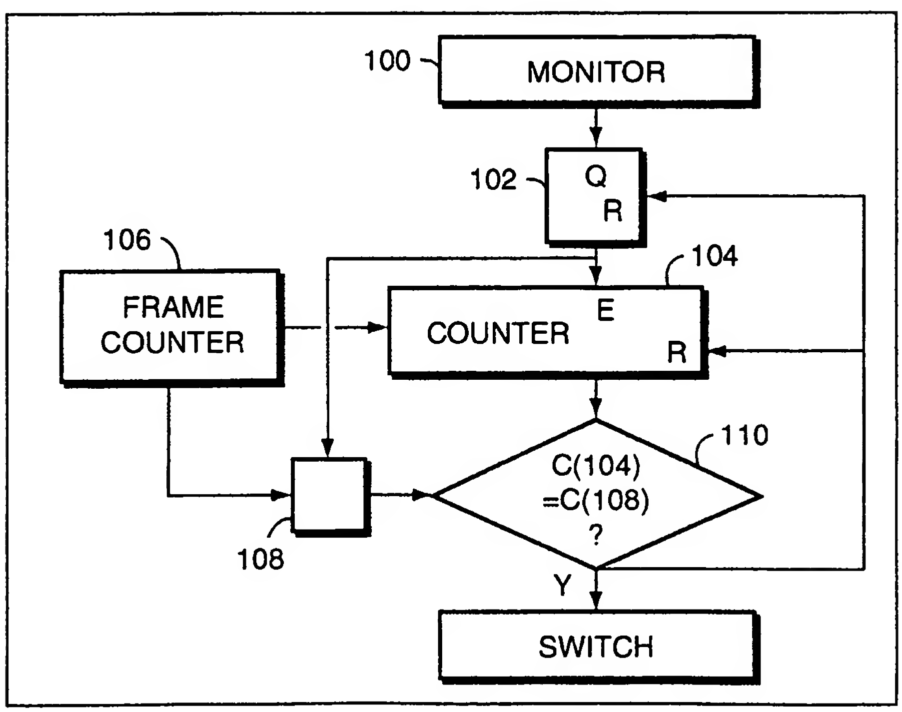
100
MONITOR
102
Q
R
106
FRAME COUNTER
104
COUNTER
E
R
110
C(104)
=C(108)
?
108
Y
SWITCH

FIG. 7

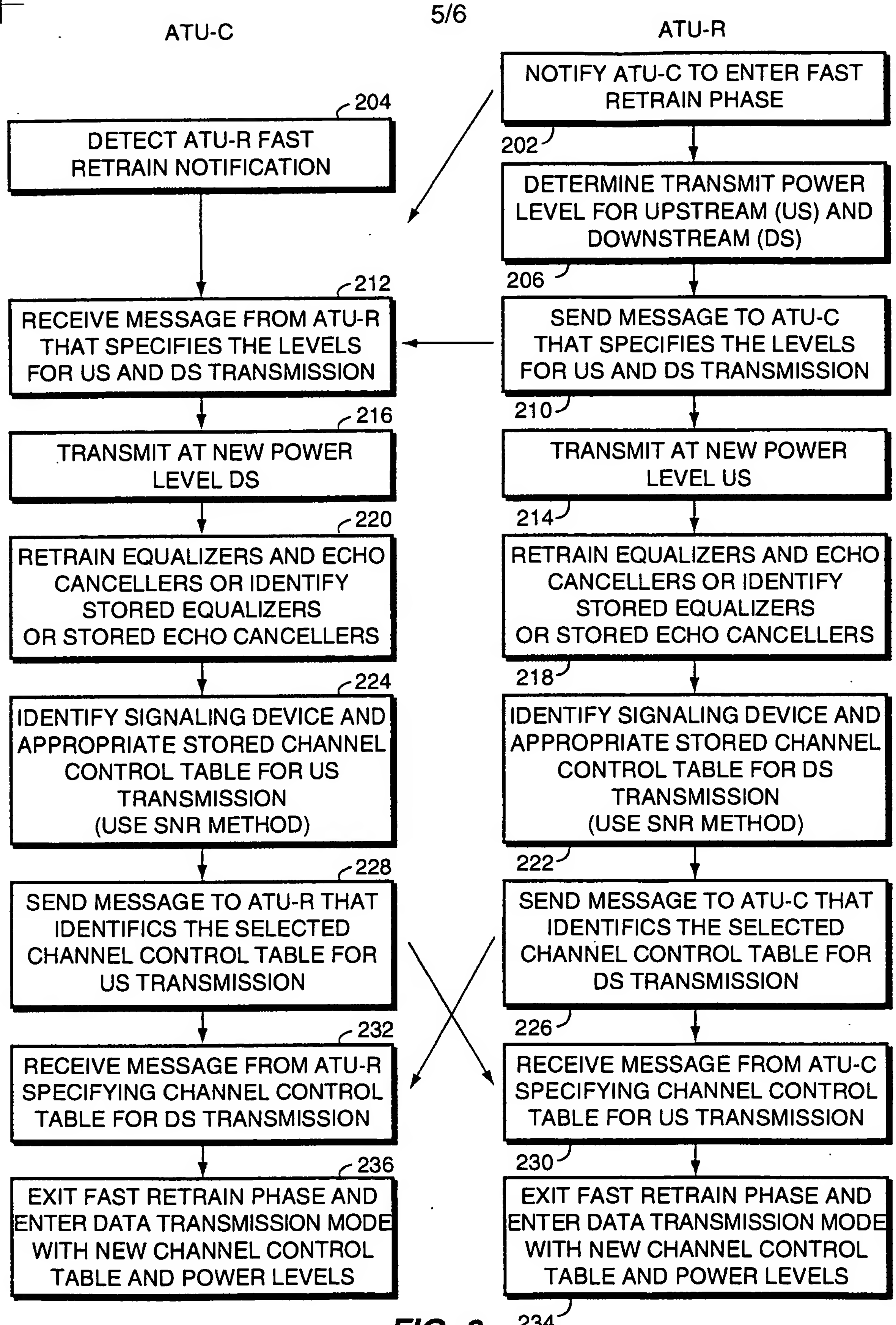
ATU-C
ATU-R
NOTIFY ATU-C TO ENTER FAST RETRAIN PHASE
202
204
DETECT ATU-R FAST RETRAIN NOTIFICATION
DETERMINE TRANSMIT POWER LEVEL FOR UPSTREAM (US) AND DOWNSTREAM (DS)
206
212
RECEIVE MESSAGE FROM ATU-R THAT SPECIFIES THE LEVELS FOR US AND DS TRANSMISSION
SEND MESSAGE TO ATU-C THAT SPECIFIES THE LEVELS FOR US AND DS TRANSMISSION
210
216
TRANSMIT AT NEW POWER LEVEL DS
TRANSMIT AT NEW POWER LEVEL US
214
220
RETRAIN EQUALIZERS AND ECHO CANCELLERS OR IDENTIFY STORED EQUALIZERS OR STORED ECHO CANCELLERS
RETRAIN EQUALIZERS AND ECHO CANCELLERS OR IDENTIFY STORED EQUALIZERS OR STORED ECHO CANCELLERS
218
224
IDENTIFY SIGNALING DEVICE AND APPROPRIATE STORED CHANNEL CONTROL TABLE FOR US TRANSMISSION (USE SNR METHOD)
IDENTIFY SIGNALING DEVICE AND APPROPRIATE STORED CHANNEL CONTROL TABLE FOR DS TRANSMISSION (USE SNR METHOD)
222
228
SEND MESSAGE TO ATU-R THAT IDENTIFICS THE SELECTED CHANNEL CONTROL TABLE FOR US TRANSMISSION
SEND MESSAGE TO ATU-C THAT IDENTIFICS THE SELECTED CHANNEL CONTROL TABLE FOR DS TRANSMISSION
226
232
RECEIVE MESSAGE FROM ATU-R SPECIFYING CHANNEL CONTROL TABLE FOR DS TRANSMISSION
RECEIVE MESSAGE FROM ATU-C SPECIFYING CHANNEL CONTROL TABLE FOR US TRANSMISSION
230
236
EXIT FAST RETRAIN PHASE AND ENTER DATA TRANSMISSION MODE WITH NEW CHANNEL CONTROL TABLE AND POWER LEVELS
EXIT FAST RETRAIN PHASE AND ENTER DATA TRANSMISSION MODE WITH NEW CHANNEL CONTROL TABLE AND POWER LEVELS
234

FIG. 8

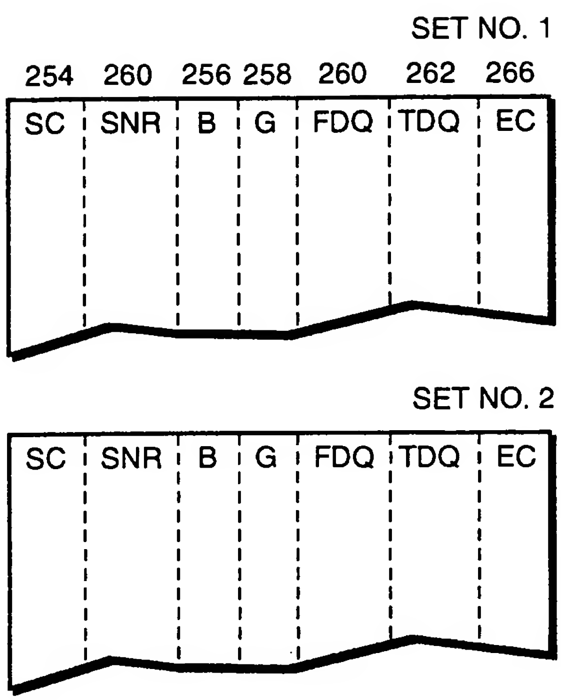

FIG. 9A

49e 49a 49b 49c 49d 49f

SC	B1	B2	B3	B4	B5	B'
9	8	7	7	6	5	5
10	8	6	6	4	4	4
11	7	7	6	5	5	5
12	8	7	6	5	5	5
40	7	7	6	6	5	5
41	7	7	6	5	5	5
42	7	7	6	5	5	5
43	6	7	6	5	5	5
:	:	:	:	:	:	:

FIG. 5C

270 272 274 276

{SET No., SNR1, SNR2, SNR3, ...}

FIG. 9B

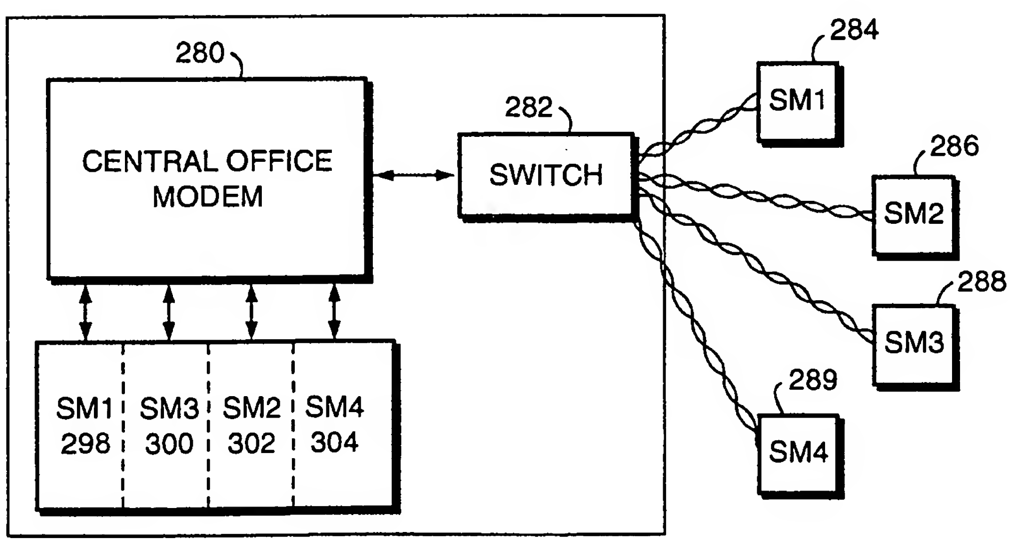

FIG. 10